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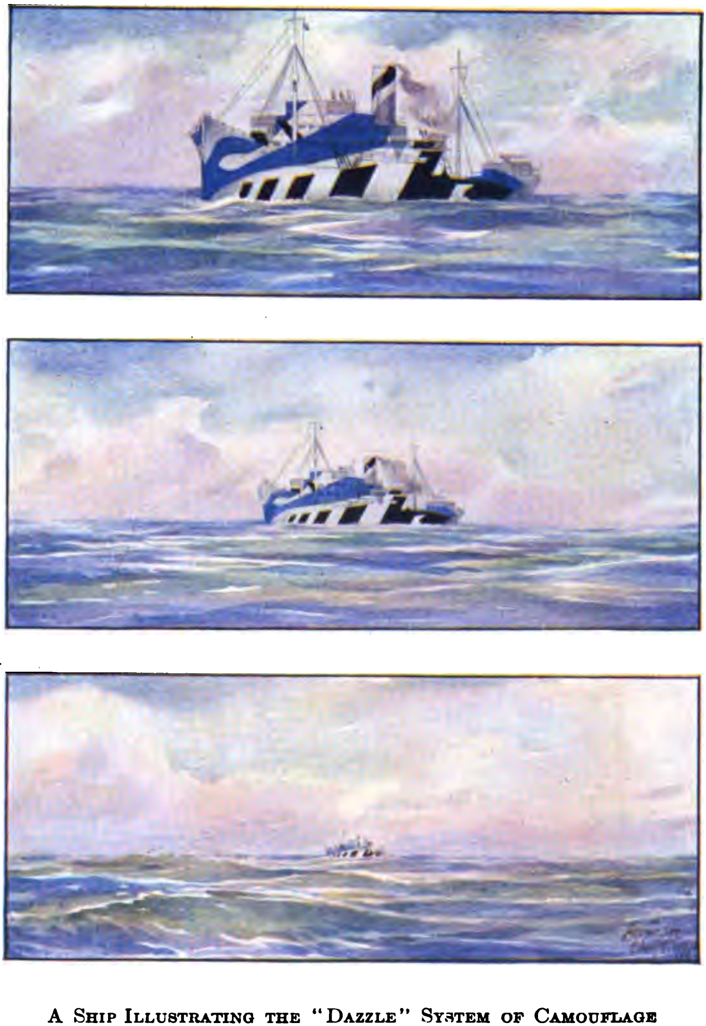

A SHIP ILLUSTRATING THE "DAZZLE" SYSTEM OF CAMOUFLAGE

The pictures show the same ship, headed in the same direction, but at three different distances. When seen at a great distance, especially through the periscope of a submarine, the ship appears to be headed in a direction quite different from its actual course, because of the false-perspective design painted on it (See page 481.)

ESSENTIALS OF PHYSICS

BY

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PREFACE

THE most essential thing in the study of any science is that there should be a thorough understanding of the fundamental principles upon which it is based. In this text experimental demonstrations are used to show the relation between the conditions imposed and the results obtained. These demonstrations lead to the statements of fundamental principles which are here given either as simple formulas or as expressions of these formulas in ordinary language.

It has also come to be generally understood that there is no branch of natural science that has a more direct application to the needs of modern life than Physics. It is for this reason that emphasis is placed in this book upon the things that are essential in understanding the applications of the principles of Physics to that which is a part of our everyday experience. At the end of each section there is a group of questions, which not only serve to recall the principles considered in the section and to stimulate the interest of the pupil, but also suggest directions in which these principles can be applied. Moreover, the problems that are given are practical problems based on conditions that are to be met with constantly.

The general applications of Physics to the doing of things are graphically presented throughout by a series of full-page illustrations. Some of these show the advances that have been made in well-known machines; as an example, the modern locomotive compared with Steven-

son's Rocket. Automobiles, airships, the submarine, and the electric railroad train exemplify the most recent methods of applying gasoline and electricity as motive power, while the dirigible and the airplane are examples of what has been done to secure a means of traveling through the most unstable of fluids, the air. The locks of the Panama Canal are triumphs of mechanical engineering. The work of the electrical engineer is shown in the electric power stations and the electric train. The development of the audion has made it possible to hold telephone conversations for almost unlimited distances; and by the teleostereograph one may transmit photographs long distances by wire in a few minutes. The non-magnetic ship, the *Carnegie*, is shown as an example of how the scientific study of magnetic phenomena can be made to serve the navigator. The illustration of the moving picture studio indicates how the exacting requirements for lighting are met. Another recent application of the principles controlling light is seen in the camouflage illustrated in the frontispiece.

Nearly all engineering is applied physics and hence has a place in the treatment of the subject.

The hope is expressed that those who study the essential principles of Physics, as treated in this book, will master them so thoroughly that they will take pleasure in tracing the dependence of our way of living upon these underlying principles.

Acknowledgment is made of many helpful suggestions made by teachers of Physics and to publishers who have granted the use of subjects for illustration.

GEORGE A. HOADLEY.

SWARTHMORE COLLEGE.

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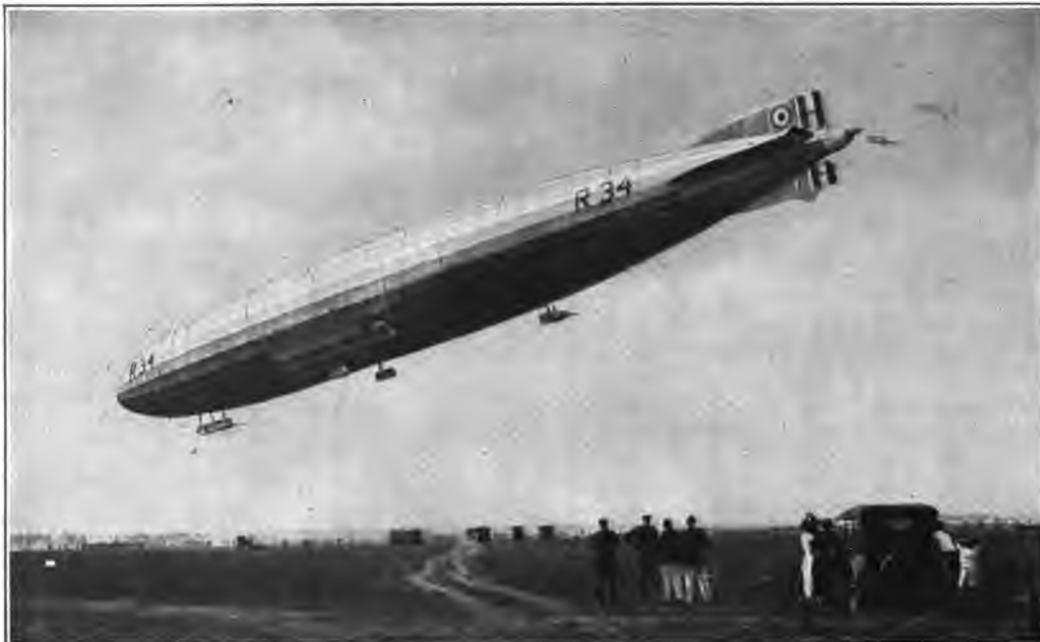
FULL-PAGE ILLUSTRATIONS



The British R 34 at the End of the First Flight by Dirigible across the Atlantic (1919)

A dirigible is lighter than an equal volume of air at the earth's surface, and hence is supported by the air

ESSENTIALS OF PHYSICS

CHAPTER I

INTRODUCTORY

WHEN we begin the study of physics in school, we already have a certain amount of information concerning physical phenomena. We know, for instance, that water can be changed into ice or into steam; we have seen the colors of the rainbow; we know that an unsupported body will fall. It is the purpose of the study of physics to add to this information and to put our knowledge into orderly arrangement.

1. Physical and Chemical Changes. — The *physical phenomena,* the laws of which we are to investigate, are the phenomena of matter and energy which may occur without changing the identity of a substance. These phenomena are caused by various *physical forces,* and include very many *physical changes.* Whenever a change takes place in matter without destroying the identity of the substance, it is known as a **physical change.** The fall of a stone thrown into the air, the changing of water into steam, the shrinking of a board while seasoning, the attraction between a magnet and a nail, are all physical phenomena, and the changes that take place are physical changes. If, however, the board is burned, or the nail is eaten by acids, the identity of the substance is destroyed, and the change is a **chemical change.**

2. **Matter** is that which *occupies space* and may be perceived by one or more of the senses. There are various kinds of matter, called **substances**, such as wood, stone, water, air, etc., while **bodies** are composed of definite volumes of these substances.

3. **Atoms and Molecules.** — The fact that bodies can be compressed gave rise to the belief that the space they occupy is not filled entirely by the matter of which they are composed, and that its particles do not really touch one another. These particles are called *molecules*, and they are the smallest parts into which a body can be divided without destroying the substance as such. If the forces which keep the molecule intact are overcome, the molecule may be broken up into *atoms*, which are understood to be the smallest quantities of matter that can enter into combination. The name *electron* has been given to particles of matter smaller than the atom, which act as carriers of negative electricity.

4. **Size of Molecules.** — Molecules are so small that they cannot be seen by microscopes of the highest power. Lord Kelvin (Sir William Thomson), however, calculated their size in some substances, and from a study of the thickness of the film in soap bubbles he found that if a globe of water the size of a football were magnified to the size of the earth, the molecules would occupy spaces intermediate in size between small shot and footballs.

5. **States of Matter.** — In the air we breathe, the water we drink, and the bread we eat we have examples of the three different forms or states that matter can assume; namely, *gaseous, liquid,* and *solid.* A **solid** is a body which,

at ordinary temperatures and under slight pressures, does not change its shape. If the shape is changed under these conditions, the body is a **fluid.** Fluids may be divided into two classes. Those that retain a definite surface on being poured into a vessel are **liquids,** while those that have a tendency to expand indefinitely are **gases.**

Bodies form an almost continuous gradation from the most rigid solid to the most tenuous gas, and the above classification may be extended as in the following table:

Rigid solid	Steel
Soft solid	Putty
Viscous liquid	Tar
Mobile liquid	Water
Liquid in minute separate particles mixed with gas	Fog or cloud
Gas	Air

Fluids flow; it is commonly supposed that solids never do. This is not strictly true, since it has been shown that under certain pressures solid bodies also flow. *The state of matter is largely determined by conditions of temperature and pressure.* A stick of sealing wax fastened at one end so that it will stand horizontally and having a two-pound weight attached to the other end will become permanently bent in a short time; an asphalt pavement on a sloping street will flow down hill during a hot day; and a bullet placed upon a cake of shoemaker's wax, resting upon two corks in a dish of water, will in a few months pass entirely through the wax, while the corks will pass upward into it. All these are examples of what are called solid bodies, yet under the proper conditions they are seen to flow.

6. Kinetic Theory of Matter. — According to the kinetic theory of the structure of matter, *the molecules of all bodies*

are in rapid vibration and the three states which matter assumes may be considered as resulting from the kind of motion of the molecules and their relative velocities.

In solids the motion of the molecule is restricted to a limited space, and although it is in constant vibration, its position with respect to the other molecules of the body is relatively fixed. Hence the shape of a rigid solid, under normal conditions of pressure and temperature, is unchanged.

In liquids the molecule is free to move in any direction. This means that the molecules of a liquid will glide over one another, and that the liquid will take the shape of any vessel into which it is poured.

In gases the molecule has a high velocity, moving in a straight-line path until it comes in contact with some other molecule or with the walls of the containing vessel. On account of this high molecular velocity a gas cannot be kept in an open vessel, and however small the quantity of gas, it will always fill any vessel in which it is confined. The quantity of gas in a closed vessel determines the pressure it will exert upon the walls.

Some substances assume all three states through a change of temperature alone, as water, which may be solid (ice), liquid (water) and gaseous (invisible vapor). Others require a change of pressure as well as a change of temperature.

7. Experiments. — An experiment is a question put to nature, and the results obtained by it are her answer. If the conditions are the same, it is found that to a given question nature always makes the same answer, and thus we learn that *the order of nature is constant;* or that she has definite laws by which she works. A careful study of the experiments described in the text for class demonstrations, attended by

practical work in the laboratory, will show the student in how great variety the questions can be asked, and will show that every changed condition has its own effect.

It is by means of experiments that physicists have discovered the laws of physics. In interpreting the results of various experiments an **hypothesis** is formed to explain these results. When the hypothesis is found to account satisfactorily for all the observed facts, it becomes an accepted **theory**; when this theory is established so firmly that it cannot be overthrown, it is the expression of **physical law.**

8. **Physics** is that *science of matter and energy* which treats of the laws that express the relation between *physical phenomena* and their *causes*. In order to study and verify these laws the student makes use of experiments in which various changes in the conditions may be made and their results noted.

CHAPTER II

THE PROPERTIES OF MATTER

9. General and Specific Properties. — In considering the properties of matter a distinction should be made between those properties that belong to matter itself and those that belong to bodies only.

General properties are those found in all matter, such as *extension, division, impenetrability, porosity, inertia.*

Specific properties are those found in certain kinds of matter only, such as *ductility, hardness, malleability.*

I. GENERAL PROPERTIES

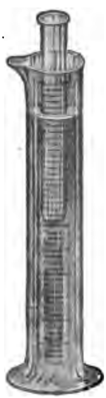


Fig. 1

10. Impenetrability. — Space that is occupied by one portion of matter cannot at the same time be occupied by any other portion. This is a property of matter rather than of bodies.

Demonstration. — Push the closed end of a test tube into the water in a graduate that is partly full, as shown in Fig. 1. The difference between the readings of the water surface before and after the tube is inserted will give the volume of the submerged part of the tube, which is the same as that of the displaced water.

A nail driven into a block of wood pierces the block and pushes the substance of the wood together. The block is usually not increased in size, but the wood now occupies only part of the space it originally occupied.

11. Porosity. — A body is said to be porous, or to have porosity, because the particles of matter of which it is composed do not fill the entire volume occupied by it. The pores in bodies vary in size from those that can be seen in a sponge or a piece of charcoal, to those in stone or metal, which may be invisible even though a microscope of the highest power be used. All bodies are porous.

The fact that a blotter will absorb ink and that a drop of oil will pass into a fine-grained piece of polished marble depends upon the porosity of the blotter and the marble.

Demonstrations. — The porosity of leather may be proved by the use of the apparatus shown in Fig. 2. The funnel *A* has a long stem over the end of which there is securely tied a piece of stretched wash leather *B*. Pour mercury into the funnel, and it will pass through the pores in the leather and fall in the form of a fine rain into the jar below. As the mercury is thus freed from all mechanical impurities, the process is of practical value.

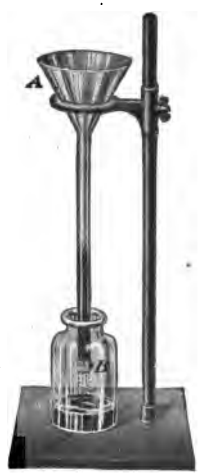


FIG. 2

Pour water into a glass tube about a meter long, until it is nearly half full, and then add colored alcohol until the surface is a half inch from the end of the tube. If this is done carefully, the line of division between the water and the alcohol can be clearly seen. Now place the finger over the end of the tube and invert it. The water will be seen to flow down through the lighter alcohol, and minute bubbles of air will rise through the mixed liquid. Invert the tube two or three times, and the length of the liquid column will be half an inch or more less than before. What does this demonstration teach?

The existence of spaces that are not occupied by the molecules of a liquid can be illustrated by filling three glasses,

one with smooth round peas, one with fine shot, and one with water. Let the first be level full, then pour shot upon the peas and shake down, being careful that the surface of the peas is not raised. When no more shot can be put in, pour in water until it comes to the top of the peas.

12. Compressibility. — Since the volume of a body can be reduced by pressure, bodies are said to be *compressible.* This property depends upon porosity. Gases are very compressible, solids to a much less degree, and liquids are almost incompressible.

By doubling the pressure upon a gas its volume is diminished one half, while changing the pressure upon water from 15 lb. per square inch to 30 lb. per square inch diminishes its volume only $\frac{1}{20000}$.

13. Indestructibility. — Matter can be made to assume different forms as the result of physical changes, and it can be combined with other matter, or broken up into different kinds of matter, through chemical forces; but *matter itself cannot be destroyed.*

The disappearance of visible matter in the boiling away of water is only a change from the liquid to the vaporous condition.

If, after burning a piece of coal, all the products of the combustion (both solids and gases) are carefully weighed, it is found that the sum of their weights is the same as the weight of the coal and the oxygen used up in the combustion.

14. Divisibility. — Bodies can be divided into smaller parts without changing the matter composing them. Divisibility by mechanical means has practically no limit. The finest crayon dust is made up of small bodies of chalk, as may be seen by examining it with a microscope.

Demonstration. — Drop a little red ink upon the surface of water in a beaker. It will mix gradually, and a thread of colored water will pass slowly downward. Let the beaker stand undisturbed for a few days, and the ink will be distributed uniformly throughout the water. Its finely divided state is shown by the fact that every drop of the solution is visibly colored.

15. Inertia is the tendency a body has to retain its condition of rest or motion. Whenever a body is at rest, it can be put in motion only by some force outside of itself; and whenever a body is in motion, the rate or direction of this motion can be changed only by the application of a force from without the body. This property is, therefore, purely negative.

Demonstration. — Place a smooth flat card on the mouth of a bottle with a small neck, and on it put a small marble exactly over the mouth of the bottle. A snap with the finger on one corner of the card will send it spinning across the room, while the ball will drop into the bottle. Place a little cotton inside the bottle. Why?

Inertia is illustrated in a great many accidents: for example, the spilling of a liquid in a dish that is moved too quickly; the shock to a railway passenger when the air brakes are applied too suddenly; the fall caused by jumping from a rapidly moving car.

Use is made of inertia, as in driving on the head of a mallet by striking the end of the handle; throwing an apple stuck on the end of a rod; or changing the position of a column of mercury in a glass tube by jerking the tube lengthwise.

16. Elasticity. — When a tennis ball is compressed into smaller volume between the hands, it feels springy, or *elastic*, because the contained air tends to resume its original volume; that is, the molecules tend to regain their original distance apart. All gases and liquids, and to a certain ex-

tent solids also, show a similar reaction against external pressure, and are said to have *elasticity of volume.*

When the shape of a solid body is slightly changed by an external force, it usually tends to resume its original form. This *elasticity of form* may be classified as follows (the corresponding external forces being given in parentheses):

(*a*) Elasticity of Compression (pressure); it is shown, for example, by the rebound of a solid rubber ball dropped upon the floor, or by the recoil of a compressed spring.

(*b*) Elasticity of Traction (pulling); it is illustrated by a rubber band stretched around a book and holding it shut.

(*c*) Elasticity of Flexion (bending); it is shown by the vibration of a tuning fork, or of a steel wire one end of which is clamped in a vise.

(*d*) Elasticity of Torsion (twisting); an example is the untwisting of a rubber tube when it is held at one end and the other let go after being twisted.

17. Hooke's Law; Elastic Limit. — If different weights are suspended from the hook of a spring balance, it will be found that the stretch of the spring for a three-pound weight is three times as great as for a one-pound weight, and that the stretch for six pounds is twice as great as for three. Further experiment will prove that up to a certain point the elongations of any spiral spring are proportional to the weights used, and that the spring returns exactly to its original length as soon as the weight is removed. But if too great a weight is put upon the spring, a permanent change in its shape is brought about and the pull is said to have exceeded the *elastic limit* of the spring. The above experiment illustrates only one case of a law stated by Robert Hooke in 1676 and now known as Hooke's Law. This is

that *whenever the forces that produce distortions in any body are within the elastic limit, the distortions produced are directly proportional to the forces that produce them.*

The loads suspended from vertical rods of the same material and form, when the elastic limit is reached, are directly proportional to the sizes of the rods, as determined by measuring the areas of their cross sections. Hence the elastic limit of a substance, for elasticity of traction, is usually expressed in pounds per square inch, or kilograms per square centimeter, of cross section.

18. Elastic Fatigue. — When a force that does not exceed the elastic limit is applied to a solid for a long time, the change of form may slowly continue; and when the force is removed, the body may not return exactly to its original form. This result is due to *elastic fatigue* and indicates a permanent change in the relative positions of the molecules of the body.

19. Measurement of Elasticity. — If a load of 4200 lb. is suspended from a copper rod 100 in. long and 1 sq. in. in cross section, the rod will be stretched slightly until it is 100.02 inches long. The external force (weight of the load) tending to produce elongation will then be exactly counterbalanced by the elastic force produced in the rod and tending to restore its original size and shape; and the load will remain at rest. The external force and the equal restoring force, in any case of elasticity, are each called a *stress;* the change of size or shape in the body is called a *strain.* So long as the elastic limit is not exceeded, the elasticity of any body is measured by the ratio of stress to strain; that is,

$$\text{Elasticity} = \frac{\text{Stress}}{\text{Strain}} = \frac{\text{Force applied}}{\text{Change produced}}. \tag{1}$$

In accordance with this expression the elastic limit may be defined as *the maximum force that can be applied to a body without producing a permanent change in its volume or form.* It is commonly said that rubber is very elastic, because it can be stretched to two or three times its length without exceeding its elastic limit; that is, it has a wide range of perfect elasticity. But as measured in physics, substances like copper, steel, marble, and ivory are far more highly elastic than rubber, because a much greater force is required to produce a given change in them.

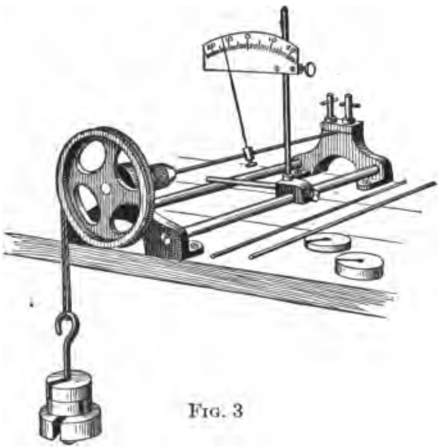


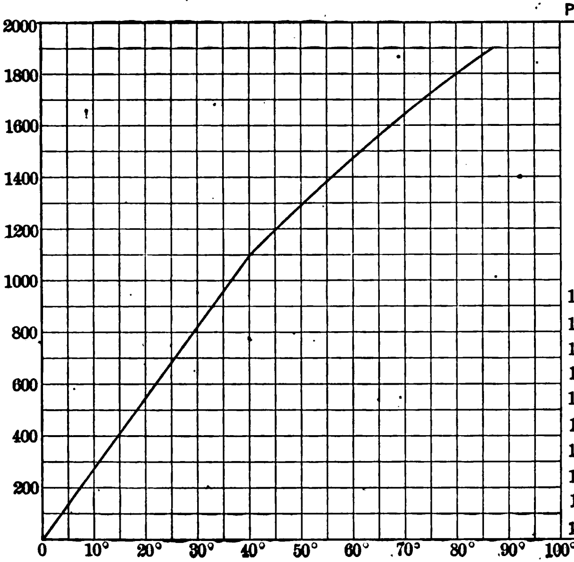
FIG. 3

In the measurement of elasticity many devices are used. One for testing the torsion, or twist, of a rod is shown in Fig. 3. This consists of some form of stable clamp to which one end of the rod is fastened. The other end of the rod is clamped in the axis of a wheel to the rim of which the twist is applied by weights. The reading pointer may be fastened to the rod at any distance from the fixed clamp and on making the experiment the relation between the weights used (stress) and the twist (strain) produced is determined. The following results of an experiment will serve as an example of the method.

The rod was of cypress, 1 cm. square and 100 cm. long. An examination of the curve (Fig. 4) shows that the twist was proportional to the pull up to 1100 g. Beyond that

pull it was not. That is, the limit of elasticity was reached at that point.

Demonstration. — Make a paste by rubbing some lampblack into kerosene, and put a thin coating upon a flat slab of iron or stone. Place a large marble upon the slab. Notice how small a part of the marble touches the slab. Drop the marble from a height of



PULL	TWIST
0	0
100g	4.1°
200	7.6°
300	11.6°
400	15.2°
500	18.9°
600	22.5°
700	26.0°
800	29.8°
900	33.2°
1000	36.9°
1100	40.4°
1200	45.0°
1300	50.2°
1400	56.1°
1500	61.2°
1600	66.5°
1700	72.8°
1800	79.1°
1900	87.3°

FIG. 4

6 or 8 ft., and notice both the height to which it rebounds and the increased size of the contact between the marble and the slab.

Repeat with a steel ball such as would be used in ball bearings, and with a small rubber ball.

20. Cohesion and Adhesion. — *Cohesion* is the mutual attraction that particles of the same kind have for each other at molecular distances. It is measured by the force required to pull a body apart.

If the attraction is between particles of different kinds, it is called *adhesion.* Both of these attractions are molecular; there is no essential difference between them, and no need of two names. Cohesion is very great in solids, and serves to give them form and strength. In liquids cohesion is not strong enough to determine the form, except in very small quantities, when they take the form of drops. In gases cohesion is very slight. In many cases adhesion is greater than cohesion, as in the case of two boards glued together, or two pieces of china cemented to each other; if they are again broken, the break will be more likely to take place in the board or china than in the joint. Finely divided matter is often made into a solid body by compression, as in the making of emery wheels. If a piece of rubber gum is cut with a knife, the two pieces may be made to cohere perfectly by pressure.

FIG. 5

Demonstration. — Press together two pieces of plate glass as in Fig. 5, and see whether both can be lifted by raising the upper piece by the corner. Put two or three drops of water between the plates, and they will cling together more firmly. Why?

II. SPECIFIC PROPERTIES

21. Tenacity. — When a body resists forces that tend to pull it apart, the substance of which it is composed is said to be *tenacious.* Tenacity is a direct result of cohesion, a tenacious substance being one that has great cohesion. *The tenacity of a substance is measured by the breaking weight per unit area of cross section.*

The tenacity, or tensile strength, of steel is of great importance on account of the extensive use of this material in building operations. There are many grades of steel, but

most of them have a tensile strength between 60,000 and 100,000 pounds per square inch.

Demonstration. — To determine the breaking weight of No. 24 copper wire, make a loop in one end and suspend it from a hook overhead. Fasten a pail to the other end so that it will be three or four inches above a table. Place known weights in the pail until the wire begins to stretch, then slowly pour in sand until the wire breaks.

FIG. 6

By measuring the diameter of the wire and taking the weight of the total load, the tensile strength can be computed, by dividing the breaking weight by the area of cross section.[1] (For example, if a wire $\frac{1}{16}$ in. in diameter is broken by a load of 104 lb., the tensile strength is equal to $104 \div \frac{3.1416}{32 \times 32} = 33{,}898$ lb. per square inch.)

In bodies of the same material, tenacity varies with the form of the body. When the areas of cross section are equal, a tube has greater tenacity than a solid cylinder of the same material, and a wire with circular cross section has greater tenacity than one with a square cross section.

Tenacity diminishes with the length of time the load is carried, so that a wire may finally break with a load that it would carry safely at first. Tenacity also diminishes as the temperature increases, on account of the increased rate of molecular vibration.

[1] The area of a circular cross section is equal to 3.1416 times the square of half the diameter.

22. Malleability. — A substance that may be beaten or rolled into thin sheets is said to be *malleable.* Brass can be rolled into sheets thinner than the paper of this book. Gold leaf is so thin that it is transparent.

23. Ductility. — A substance that can be drawn into wire is said to be *ductile.* Some metals possess great ductility. Platinum has been drawn into wire only 0.00003 of an inch thick. In order to do this, a small platinum wire was covered with silver, forming a compound cylinder, the silver surrounding the platinum much as the wood surrounds the graphite in a lead pencil. This cylinder was drawn into a very small wire, which had still a platinum center surrounded by silver; then the silver was dissolved by an acid which does not affect platinum, and the platinum was left as a wire of microscopic fineness.

Demonstration. — Take a piece of glass tubing about 10 cm. long by the ends and hold the middle in the flame of a Bunsen burner near the top. When it becomes cherry red remove it from the flame and draw it out with a steady pull. Prove that it is a tube by blowing through it when one end is under the surface of water.

24. Hardness is a relative property; there is no such thing as an absolutely hard or soft body. A body that can scratch or wear another is the harder of the two. Glass is harder than wax but softer than the diamond. The diamond is the hardest of all natural substances, and diamond dust is used to cut other stones. Brittleness must not be mistaken for hardness. Steel, which is hard, is tough; while glass, which is also hard, is brittle.

Steel is rendered very hard and brittle by being heated to a red heat and then being plunged into water. In order to render it serviceable for cutting tools, or for springs, it is

reheated slowly until it has the desired degree of hardness, which is indicated by its color, when it is again plunged into water or oil. This process is called *tempering*.

Iron may be rendered soft, or *annealed*, by cooling it gradually and evenly from a high temperature. This renders iron wire pliable, and if the same process is applied to glass, the strains are taken out and it is much less liable to crack on being heated.

A swiftly moving body will cut one that is at rest even if the latter is harder, as in the case of a soft iron disk rotating at a high speed, which is sometimes used to cut off hard steel bars. The cutting power of an emery or carborundum wheel depends both upon the hardness of the material and the high speed at which it is run. A buffing wheel used for polishing metals is an example of this action.

25. Crystallization. — Some matter in the form of a solution has the property of forming crystals. Crystals may also be formed when a melted metal solidifies on cooling. Zinc shows this very plainly on account of the size of its crystals. If a bar of cast zinc is broken, not only can the crystals be seen, but a line of weakness will be shown wherever they meet from the sides of the mold.

By a *saturated solution* is meant one that will take up no more of the substance. When salt is put into water until, after thorough stirring, some of the salt is still not dissolved, the solution is said to be saturated. When such a solution begins to evaporate, crystals are formed. Raising the temperature of a solution usually causes more of the substance to be dissolved and crystals form when it cools.

Demonstrations. — Make a saturated solution of salt and put it in a beaker. Set this in a quiet place, and after a few hours you will find the surface of the liquid covered with little cubical

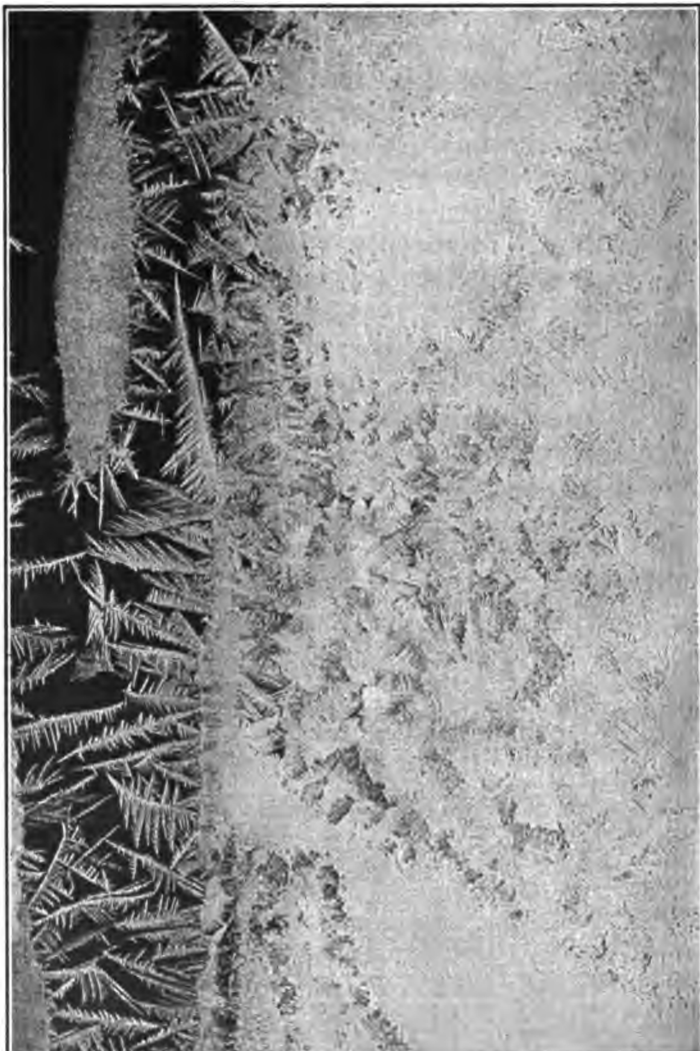


FIG. 7. — Ice Crystals. Frost on a Window

crystals of salt. Let the solution stand for twenty-four hours and groups of crystals will be floating on the surface. Lift one of these out, invert it, and you will find a beautiful little pyramid formed of salt cubes.

FIG. 8. — Creeping of Crystals

Make a saturated solution of salt and fill a teacup nearly full. Set the cup in a saucer and put them in some quiet place. In a few days the salt crystals will creep over the edge of the cup and form a coating upon the outside and in the saucer.

Make a solution of potassium bichromate. Pour a little on a clear glass plate, and with a small stick work the liquid into the form of a flat, round mass. Set it in a quiet place over night, and then observe the crystals with a reading glass. Beautiful slides can be made in this way for projection on the screen with a lantern.

III. MASS, WEIGHT, AND MEASUREMENTS

26. Mass and Weight.—The *mass* of a body is the amount of matter in it, as determined by "weighing" the body in a lever balance. The *weight* of a body, though depending upon its mass, is a different thing, and the two words should not be confused. The weight of a body is *the measure of the mutual attraction between the body and the earth.* This attraction varies slightly in degree at different parts of the earth, while the amount of matter, or *mass,* in a pound of lead, for instance, is the same everywhere.

27. Measurements.— The modern study of physics, with the accurate knowledge obtained therefrom, depends largely

upon precise measurements, made in the units of **space, mass,** and **time.** We shall consider two systems of measurements, the English because it is in general use, and the French or metric because of its simplicity and of its growing use in all scientific work.

28. The C. G. S. System of Measurement. — Scientists working in various countries felt the inconvenience of having various standards of length, mass, and time, and finally adopted, for scientific work, the French system, more precisely known as the centimeter-gram-second or C. G. S. system. The convenience of this system is so great that it is taking the place of the foot-pound-second or F. P. S. system, used in Great Britain and the United States.

29. Space of One Dimension: Length. — The French measures of length were devised in the latter part of the eighteenth century, by physicists who aimed to accomplish two things: first, to obtain a unit based upon a natural measure; and second, to take advantage of the convenience of the decimal scale. To secure the first result, they took for the *meter*, or unit of length, the ten-millionth part of the distance from the equator to the pole, measured on the meridian passing through Paris. Subsequent and more accurate measurements have shown that the distance as originally measured was not absolutely correct, and that the length of the standard meter is contained in the quadrant of the earth 10,000,880 times. While this prevents the meter from being the decimal part of a natural unit, it does not affect the value of the meter as a practical unit.

The original *standard meter* is a rod of platinum kept in the archives at Paris, and the distance between its ends at the temperature of melting ice is 1 meter. The tempera-

ture has to be stated because a metal bar changes in length with a change in temperature.

For the multiples of the meter the Greek prefixes *deka, hekto,* and *kilo* are used, and for the decimal parts the Latin prefixes *deci, centi,* and *milli;* as follows:

10 millimeters	= 1 centimeter	10 meters	= 1 dekameter
10 centimeters	= 1 decimeter	10 dekameters	= 1 hektometer
10 decimeters	= 1 meter	10 hektometers	= 1 kilometer

For small divisions of the millimeter the *micron,* one one-thousandth of a millimeter, and the *millimicron,* one one-millionth of a millimeter, are used. These are designated by the Greek letters μ (mu) and $\mu\mu$ respectively. Millimeter, centimeter, meter, and kilometer are abbreviated, respectively, **mm.**, **cm.**, **m.**, and **km.**

The English unit of length is the *yard,* which is defined by English law as "the distance between the centers of the transverse lines in the two gold plugs in the bronze bar deposited in the office of the exchequer" in London, when the temperature is 62° Fahrenheit. For practical use the *foot* — one third of a yard — is taken as the unit.

Copies of the standard yard have been made and distributed to those countries that use the English systems. The standard now used in the United States, however, is

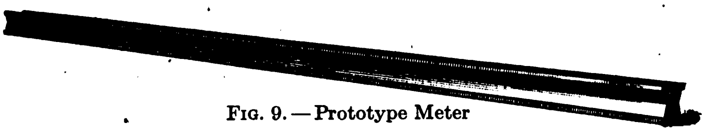


FIG. 9.—Prototype Meter

derived from the International Prototype Meter. That is, the yard in this country is made $\frac{3600}{3937}$ as long as the meter; but there is only a microscopic difference between this and the English standard.

Seventeen nations, of which the United States was one, united in establishing the International Bureau of Weights and Measures,

and in 1889 the international prototype standards, which were copies of the standard meter and kilogram, were completed by the Bureau and distributed by lot to the various nations concerned. The United States received meters Nos. 21 and 27 and kilograms Nos. 4 and 20. The seals of meter No. 27 (Fig. 9) and of kilogram No. 20 were broken by President Harrison on Jan. 3, 1890, and these standards are now in the custody of the National Bureau of Standards in Washington.[1]

Fig. 10.— 1 Decimeter

The relation between the various measures of length in this country is shown below:

1 mm. = 0.03937 inch
1 cm. = 0.3937 inch
1 m. = 39.37 inches or 3.28083 feet
1 km. = 3280 feet or 0.62137 mile

1 in. = 2.54 cm.
1 ft. = 0.3048 m.
1 mile = 1.60935 km.

The student will find it useful to become familiar with a few approximate values besides the exact value of the meter in inches. The millimeter is nearly equal to $\frac{1}{25}$ of an inch, the centimeter to $\frac{2}{5}$ of an inch, the kilometer to $\frac{5}{8}$ of a mile.

To use any scale intelligently one must have a distinct idea of the values of the units. To secure this in the metric scale the student should measure many familiar objects with the metric scale in terms of the *centimeter*, as that is commonly taken as the unit of length in physics.

30. Space of Two Dimensions: Surfaces. — Since a surface has but two dimensions, the *unit of surface* is a square

[1] See Bulletin No. 26, U. S. Coast and Geodetic Survey, "Fundamental Standards of Length and Mass."

of which the unit of length is the side. In most physical measurements the unit of surface is the *square centimeter* (sq. cm. or $cm.^2$), though for small areas the square millimeter (sq. mm. or $mm.^2$) is commonly used. The table is similar to the table for length, but with a uniform scale of 100; that is, 100 sq. mm. = 1 sq. cm., or 100 $mm.^2$ = 1 $cm.^2$, etc.

31. Space of Three Dimensions: Solids. — A volume has three dimensions, length, breadth, and thickness. The *unit of volume* is a cube with the unit of length for each edge. In the metric system it is the *cubic centimeter* (c.c. or $cm.^3$), and the scale of the table is 1000.

Units of Mass and Weight. — The French *standard mass* is the *kilogram* (kg.). This is the mass of a cubic decimeter of pure water at 4° C. The *gram* (g.), equal to one thousandth of the kilogram, is the practical unit in physics. Decimal subdivisions and multiples of the gram are named by using the same prefixes as with the meter. The standard *pound* in this country is derived from the International Prototype Kilogram. The exact relation is, 1 lb. = 0.4535924277 kg.; but for ordinary purposes the following are used as equivalents:

1 kg. = 2.2046 lb. 1 lb. = 0.4536 kg.

Since at any one place the weights of bodies are directly proportional to their masses, and since the variation in weight with location on the earth's surface is not very great, the terms that are applied to masses (*gram, pound, ounce,* etc.) are commonly applied to the corresponding weights also.

It is often important in physics to compare the masses of equal volumes of different substances, or the volumes of equal masses. By the *density* of a body is meant *the ratio of its mass to its volume,* or *the mass of a unit volume.*

32. Capacity. — Measures of capacity in the metric system depend upon the unit of length, the *unit of capacity*

being a cubic decimeter, which is called the *liter*. As this is 1000 c.c., a liter of pure water at the temperature of greatest density weighs 1 kg.

33. Time. — The *unit of time* in physics is the *second*. This is the second of mean solar time, and is $\frac{1}{86400}$ of the mean solar day. Mean solar time is the time in common use, recorded by clocks and watches.

According to Albert Einstein's theory of relativity, time and mass and dimensions vary with the velocity of the motion of the body concerned. This variation is important for very great velocities, comparable with the velocity of light, but for moderate velocities it is so infinitesimally small as to have no effect. Hence time and the masses and measurements of ordinary bodies in physics are not affected by this theory.

Questions

1. A piece of paraffin wax is heated until it melts. The melted paraffin is then heated until it burns. Name the changes that have taken place.
2. What kind of change takes place when salt is put in water? How may the salt be regained?
3. What different forms can water be made to assume by changing its temperature? Describe each.
4. Suppose you wish to pour a liquid into a bottle, using a funnel. Should you use a funnel that fits the mouth of the bottle air-tight? What is the reason for your answer?
5. Show how you would find the volume of a piece of coal by displacement.
6. Suppose you make a solution of salt and mix some chalk dust in it. What will be the result of filtering the solution? Explain.
7. What is changed when a gas is compressed, the size of the molecules or the distance between them?
8. How does the surface of writing paper differ from that of blotting paper?
9. Give examples of cohesion and adhesion.

10. Upon what property of matter does the strength of a kite string depend?

11. How could you find which is harder, glass or diamond?

12. Are the divisions of the scale of a spring balance of equal length? Why?

Problems

1. A runner makes a 100-yard dash in 9.5 seconds. What is his speed in feet per second? In meters per second?

2. The Eiffel Tower is 335 m. high. How many feet high is it?

3. The Washington Monument is 555 ft. high. Give its height in meters.

4. It is 535 feet from the top of the statue of William Penn on the City Hall tower in Philadelphia to the pavement at the foot of the tower. How far is it in meters?

5. A boy 5 ft. 2 in. tall weighs 104 lb. Find his height in centimeters and his weight in kilograms.

6. The distance from the Pennsylvania station, New York, to the Broad Street station in Philadelphia is 91.3 miles. How many kilometers is it?

7. The airline distance from Paris to London is 338 kilometers. What is the distance in miles?

8. A pile of wood 8 ft. long, 4 ft. wide, and 4 ft. high contains one cord. How many cubic meters does it contain?

9. A block of marble 4 ft. long, 3 ft. wide, and 1½ ft. high weighs 2970 lb. What is its weight in pounds per cubic foot? What is its weight in kilograms per cubic foot?

10. How many kilograms in a ton of 2000 lb.?

11. How many long tons (2240 lb.) in 10 metric tons? (1 metric ton = 1000 kg.)

12. A cubical box is 2 meters on each edge, inside. How many liters of water will be required to fill it? What will the water weigh in kilograms? In pounds?

13. A barrel of flour weighs 196 lb. What is its weight in kilograms?

14. A metal bar 2 inches square is pulled apart by a load of 56,326 lb. Compute the tensile strength of the metal, per square inch of cross section.

Rev.

CHAPTER III

THE MECHANICS OF SOLIDS

I. MOTION, VELOCITY, AND FORCE

34. Mechanics treats of the action of forces on bodies. It may be divided into two subjects, *statics* and *dynamics*. **Statics** treats of the laws governing forces when no motion is produced, and **Dynamics** or **Kinetics** treats of the laws governing forces by which motion is produced.

35. Motion. — A body is said to have *motion* while it is passing continuously from one position to another. A body is *at rest* when its position remains unchanged.

An automobile standing by the curb is at rest. When the engine is started and its power applied, the automobile begins to move. That is, by the application of sufficient force its condition is changed from rest to motion. Rest and motion are, however, entirely relative. A body may be at rest in a railroad train, but in motion with respect to the earth. A body that is at rest with respect to the earth is in motion with respect to the sun.

The motion of a body is said to be *rectilinear* when it moves in a straight line. When a body moves in a path which constantly changes in direction, it is said to have a *curvilinear* motion, or to move in a *curve*. While it may not be difficult to imagine a body moving from one fixed point in space toward another without change of direction, in strict reality we know of no absolutely rectilinear motion

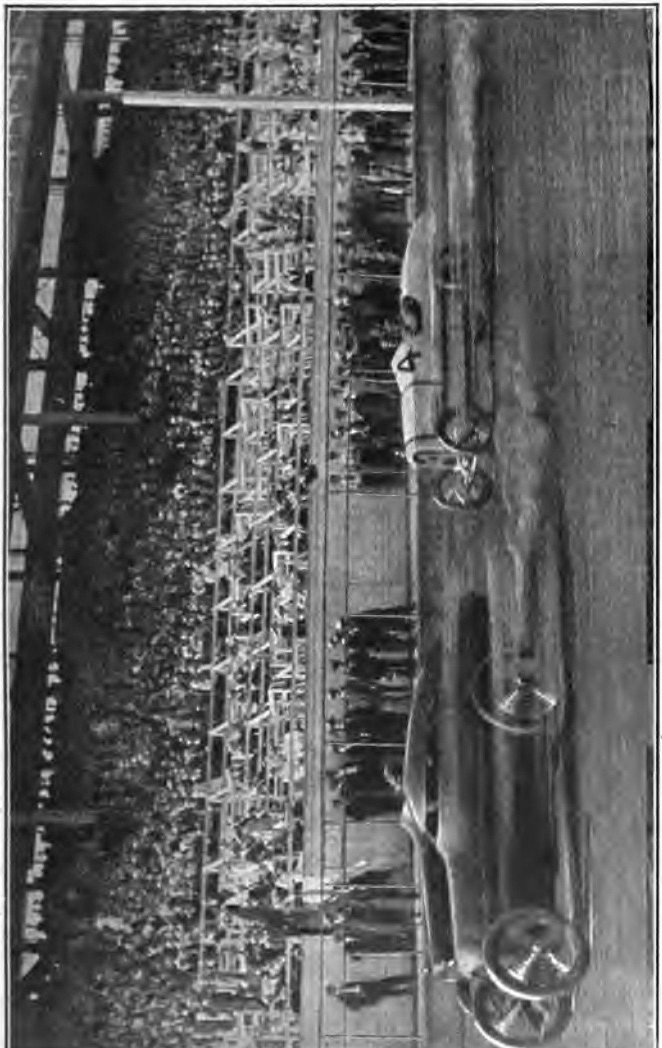


FIG. 11. — Automobile Race. Automobiles have been driven at the rate of more than 100 miles an hour

of bodies. A stone falling from a balloon is moving toward the center of the earth, but this is itself moving about the sun, hence the motion of the stone must be in a curve. For all practical purposes, however, a body which moves without change of direction with reference to a room or the surface of the earth is said to move in a straight line.

If a body moves over equal spaces in equal times, its motion is said to be *uniform*. If the distances are not equal, its motion is *variable*.

36. Speed; Velocity. — Speed is the *rate of change of position* of a moving body or its *rate of motion;* velocity is the speed in a definite direction. If the motion is uniform, the speed is measured by the distance the body goes in a unit of time. If the motion is variable, the speed *at any instant* is the distance it would move during the next unit of time if it should continue to move at the same rate.

If the speed of a body is greater for each unit of time than it was for the preceding, the motion is said to be *accelerated.* If the *acceleration,* or increase of speed, is the same for each unit of time, the motion is *uniformly accelerated.*

Motion is *retarded,* or negatively accelerated, when the speed is decreasing instead of increasing, and if the retardation is uniform, the motion is *uniformly retarded.*

Average or *mean speed* is the speed with which a body would need to move uniformly to pass over a certain space in a given time, though the actual speeds may be made up of a great many rates.

If only *motion in a definite direction* is considered, the above statements about speed will also hold true of *velocity.*

37. Space Passed Over. — The space passed over by a moving body depends upon two elements, speed and time.

A train moving with an average speed of 20 mi. per hour moves 60 mi. in 3 hr. This relation may be expressed by the equation

$$60 = 20 \times 3;$$

so in general,

$$\text{Space passed over} = \text{Average speed} \times \text{Time},$$

or, writing S for space passed over, v for average speed, and t for time, we have the formula

$$S = vt. \tag{2}$$

NOTE. — The student should observe that "Space passed over = Average speed × Time" is not to be understood literally. It is merely a short and convenient way of saying, "The number of units of length passed over = the number of units of length in the average speed per unit of time × the number of units of time." The briefer wording of such formulas as this is so convenient and so commonly employed in actual use, that it will be used in this book; but the student should always bear in mind that every element, or letter, in a formula represents merely a *number*.

38. Acceleration. — When the velocity of a body is uniformly accelerated, the rate of change in its velocity or the amount its velocity changes per second, is called its *acceleration*. If the body, starting from a *condition of rest,* has a velocity of 2 ft. per second at the end of one second, 4 ft. per second at the end of the next second, 6 at the end of the third, and so on, the gain in velocity, per second, is 2 ft. per second; that is, the acceleration is 2 ft. per second per second. In uniformly accelerated motion the *average* velocity for any period is half of the sum of the velocities at the beginning and end of that period. Hence in this case, as the velocity is 0 at the beginning, the average velocity for the first second would be 1 ft. per second, and the average velocity for the first three seconds would be 3 ft. per second.

Suppose a body to move in a certain direction from a condition of rest with a constant acceleration of a units per second per second. Its velocity per second at the end of 1 sec. will be a; at the end of 2 sec., $2a$; at the end of 3 sec., $3a$; and so on. At the end of t seconds its velocity per second will be $t \times a$ or at; that is,

$$\text{Final velocity} = \text{Acceleration} \times \text{Time},$$

or,
$$v = at. \tag{3}$$

Since the velocity per second increases uniformly from 0 at the beginning to at at the end of t seconds, the average velocity per second for t seconds will be $\frac{1}{2}at$, and the entire space passed over equals average velocity × time. This may be represented by the equation

$$S = \tfrac{1}{2}at \times t = \tfrac{1}{2}at^2. \qquad [1]\ (4)$$

Since the velocity per second for the first second increases uniformly from 0 at the beginning to a at the end, the space passed over in that second will be $\frac{1}{2}a$. We can get the same result by making the time 1 sec. in Equation 4, for the equation then becomes $S = \frac{1}{2}a$. We see from this that whenever a body starts from a condition of rest, and moves with a constant acceleration, the acceleration per second per second is twice the space passed over in the first second.

The space passed over during any second (the last of t seconds) may be found by subtracting from the distance passed over in t seconds the distance passed over in a time one second less. The space passed over in t seconds be-

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[1] By combining Equations 3 and 4 we can derive the equation

$$S = \frac{v^2}{2a}\text{; and from this, } v = \sqrt{2aS}, \tag{5}$$

a formula sometimes convenient for finding the final velocity directly from the acceleration and the entire space passed over.

ing by Formula 4, $S = \frac{1}{2}at^2$, the space passed over in $(t - 1)$ seconds will be $S' = \frac{1}{2}a(t - 1)^2$. Hence the space passed over in the last second will be

$$s = S - S' = \frac{1}{2}at^2 - \frac{1}{2}a(t-1)^2 = \frac{1}{2}a(2t - 1); \textit{ i.e.},$$

$$s = \frac{1}{2}a(2t - 1). \tag{6}$$

It is sometimes convenient to express velocity and acceleration in symbols. Thus a velocity of twenty centimeters per second may be expressed as $20\,\frac{\text{cm.}}{\text{sec.}}$, and the speed of a bicycle rider going at the rate of a mile in four minutes is a speed of $22\,\frac{\text{ft.}}{\text{sec.}}$, that is, twenty-two feet per second. In the same way an acceleration of fifteen centimeters per second per second may be written $15\,\frac{\text{cm.}}{\text{sec.}^2}$, and an acceleration of twelve feet per second per second may be written $12\,\frac{\text{ft.}}{\text{sec.}^2}$.

39. Effect of a Constant Force. — Whenever a body is moving under the influence of a constant force only and there is no change in the resistance, the resulting motion is uniformly accelerated. The constant force with which we are most familiar is the force of gravity; hence, as an illustration of the effect of constant forces, we study the motion of a falling body.

40. A Freely Falling Body; Resistance of the Air. — A body that is moving under the influence of gravity alone is a *freely falling body.* This condition can be obtained only in a vacuum, as the air constantly offers a resistance to the passage of any body through it.

Demonstrations. — Trim a piece of stiff paper and a cork until each has the same weight as a shot or a bicycle ball. Drop all three from the same height at exactly the same time, and notice when they strike the floor. Since they all have the same weight, the force tending to give them motion is the same, but as they present dif-

ferent amounts of surface to the air, the resistance of the air varies. If the sheet of paper is let fall when it is flat, it will slide down on the air in various directions, but if a small part of its width is turned up at an angle, it will fall very steadily.

Drop two balls of the same size, one of brass and one of wood, from a height of 20 ft. or more. They reach the ground at practically the same time. Why?

These demonstrations indicate in a simple way the method used by Galileo to settle by experiment the discussion which had been vigorously carried on between those who thought that the velocity of a freely falling body was proportional to its weight and those who, like Galileo, thought it was the same for all bodies. The experiment was made by dropping various bodies from the top of the leaning tower of Pisa, and showed that Galileo was right. The pull of the earth on a two-pound weight is twice its pull on a one-pound weight, but in causing the weights to fall this pull must do twice as much work on the two-pound weight as on the one-pound weight; hence the speed of the fall is the same. The resistance of the air prevents raindrops from acquiring a high velocity. A parachute (Fig. 12) likewise falls slowly because it presents a surface that is large in proportion to the weight.

41. Measuring the Velocity of Falling Bodies. — (*a*) *The Direct Method* consists of dropping a small ball of some heavy material from the top of a tower — like a shot tower — and determining by actual measurement where it strikes a support at the end of the first second, second second, etc. One of the difficulties connected with this method is the height of tower required, since for a fall of 3 sec. the tower would need to be about 145 ft. high.

(*b*) *Galileo's Method.* In all other methods the velocity of the falling body is reduced in some way. Galileo ac-

Fig. 12. — A Parachute in Action, as seen from an Airplane

The parachute was first used for making a spectacular descent from a balloon. During and after the World War of 1914–1918, parachutes were put to practical use in making descents from balloons, dirigibles, and airplanes.

complished this by letting a ball roll down an inclined plane. If the length of the plane is made great in comparison with the height, the ball will roll down the plane far more slowly than it would fall in a vertical direction.

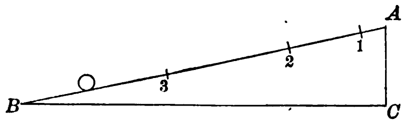


FIG. 13

If the experiment is carefully made, the results will be such as are shown in Table A, since the resistance of the air is slight. Let $A\,1$ (Fig. 13), the space passed over in the first second, be called d. Then it will be found that $A\,2$, the space passed over in 2 seconds, is 4 times as great, or $4\,d$; that $A\,3$, the space passed over in 3 seconds, is 9 times as great, or $9\,d$, etc., no matter what the proportional height of the plane is. These results are shown in the fourth column of Table A, from which are found the spaces passed over in the different seconds, as shown in the third column. Since the force is a constant one (it is a certain fraction of the weight of the ball), the acceleration is constant, and is twice the distance passed over in the first second, or $2\,d$, per second per second. Notice that this is also the difference between any two successive values in column 3. The acceleration $2\,d$ in turn gives the values in the second column.

TABLE A

Time in seconds	Velocity per sec. at end of sec.	Space passed over during the sec.	Whole space passed over
1	$2d$	d	d
2	$4d$	$3d$	$4d$
3	$6d$	$5d$	$9d$
4	$8d$	$7d$	$16d$

By increasing the proportional height of the plane the velocity of the ball is increased, until, when the plane becomes

vertical, the ball is no longer a rolling but a falling body and the acceleration equals g, the acceleration due to *gravity*.

Replacing a in Formulas 3, 6, and 4 by g, we have the formulas for falling bodies:

$$v = gt, \tag{7}$$

$$s = \tfrac{1}{2}\, g(2\,t - 1), \tag{8}$$

$$S = \tfrac{1}{2}\, gt^2. \tag{9}$$

The value of g varies at different places on the earth, from about 978 cm. at the equator to about 983 cm. at the poles. At New York its value is 980.2 cm., or 32.16 feet. By making this substitution, these formulas may be written:

$$\begin{array}{lcl} \overbrace{\text{FOR RESULTS IN FEET}} & & \overbrace{\text{FOR RESULTS IN CENTIMETERS}} \\ v = 32.16\,t & \text{or} & v = 980.2\,t, \\ s = 16.08(2\,t - 1) & \text{or} & s = 490.1(2\,t - 1), \\ S = 16.08\,t^2 & \text{or} & S = 490.1\,t^2. \end{array}$$

These formulas for freely falling bodies are very important, and should be familiar to every student.

42. Graphical Analysis of a Falling Body. — The motion of a falling body can be analyzed graphically as in Fig. 14. Draw a vertical line and take a certain distance AB, from the top of the line A, as the distance the body falls the first second, equal to $\frac{1}{2}\,g$. Measure from B twice this distance to represent the velocity

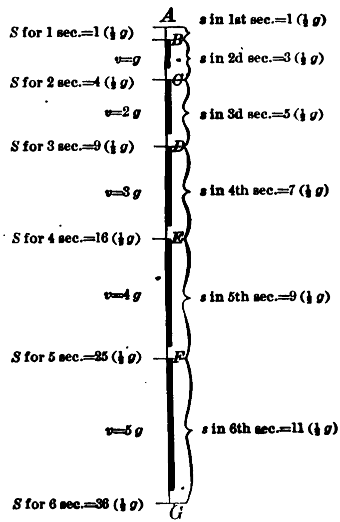


FIG. 14

gained during the first second. Make this a heavy line and extend a light line to C, a point $\frac{1}{2}g$ farther on. Then BC will be made up of two parts, one of which represents the distance passed over because of the velocity gained during the first second, and the other the additional distance the body falls because of gravity acting on it for the second second. Points D, E, etc., may be found in a similar manner.

43. Initial Velocity. — If a body is thrown vertically downward, its velocity and the space passed over in any time will differ from those of a falling body that starts from a condition of rest. If we let V represent the velocity per second of such a body at the beginning, we may write

Velocity per second at the end of 1 sec. $= V + g$,
Velocity per second at the end of 2 sec. $= V + 2g$,
Velocity per second at the end of 3 sec. $= V + 3g$,
Velocity per second at the end of t sec. $= V + tg$,

or
$$v = V + gt, \tag{10}$$

a formula that differs from Formula 7 only in supposing an initial velocity. An initial velocity makes corresponding changes in Formulas 8 and 9 also, and they become

$$s = V + \tfrac{1}{2}g\,(2t - 1), \tag{11}$$

and
$$S = Vt + \tfrac{1}{2}gt^2. \tag{12}$$

44. Projectiles. — (*a*) *Bodies thrown Horizontally.* — The path of a projectile may be obtained by combining the uniform motion due to the impulsive force with the motion due to the force of gravity; and since gravity is a constant force, the body will generally move in a curved path. The path of a body thrown horizontally may be constructed graphically as follows (neglecting the resistance of the air).

Take the axes as in Fig. 15. Let x represent horizontal motion and y vertical motion. Suppose the horizontal velocity is 50 ft. per second. Compute the values of S from the formula $S = \frac{1}{2} gt^2$, and determine the position of the projectile at the end of each second. A curve joining the positions will represent the path required; if the page is held in a vertical plane, the curve is the path in miniature. This curve is of the form called parabolic.

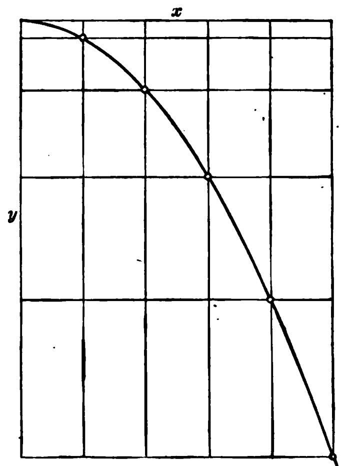


FIG. 15

Demonstration. — Fix a sheet of cross section paper to the apparatus shown in Fig. 16 by the clips on the board and fasten a sheet of carbon tracing paper in contact with it. Project a steel ball from its support and it will roll down the inclined plane. Remove the tracing paper and note the relation between the horizontal and vertical velocities. Change the inclination of the plane and repeat.

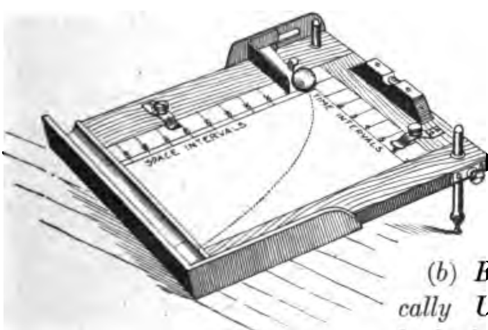


FIG. 16

(b) *Bodies thrown Vertically Upward.* — When a body is rising against the force of gravity, the loss in its velocity is the same as its gain in velocity when falling; *i.e.*, 32.16 ft. per second, if we neglect the resist-

ance of the air. The body is said to have a *negative acceleration, i.e.,* its velocity is uniformly diminishing and its final velocity is zero. Hence if a body is thrown vertically upward with a velocity of 64.32 ft. per second, it rises for 2 sec., when its velocity becomes zero and it begins to fall. It then falls for 2 sec., and reaches the ground with its original velocity of 64.32 ft. per second. The time during which a body will rise when thrown vertically upward may be expressed by the formula $t = \frac{v}{g}$.

(*c*) *Bodies thrown at an Angle.* — When a body is thrown at an angle, the velocity with which it is thrown in any direction may be considered a velocity of which the horizontal and vertical velocities are components. If in Fig. 17 AB represents the velocity with which a ball is thrown, the components AC and AD will represent the horizontal and vertical velocities respectively. The angle BAC is the *angle of elevation,* and the distance AE is the *range.* In the foregoing cases no allowance was made for the resistance of the air, but its effect upon the form of the path in this case is shown in Fig. 17. Its effect is to lessen both velocities (horizontal and vertical) by an amount which is much greater for high velocities than for low ones. Show what its effect would be in cases *a* and *b* of this section.

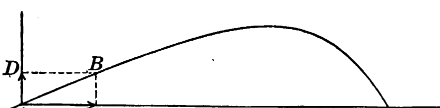


Fig. 17

The path ABE is called the *trajectory* and is similar in shape to that of a batted baseball. The trajectory of a rifle ball is much flatter on account of the high speed of the projectile. One advantage of smokeless over black powder is that it gives a flatter trajectory.

45. Momentum. — The product of the mass of a body by its velocity is called its *momentum,* or quantity of motion. In the C. G. S. (centimeter-gram-second) system (§ 28) the unit of momentum is the *bole, i.e.,* the momentum of 1 g. of matter moving with a velocity of 1 cm. per second. The expression

$$b = Mv \qquad (13)$$

is the formula for momentum. There is no name for the unit in the F. P. S. (foot-pound-second) system, but the unit would be practically the momentum of 1 lb. moving at the rate of 1 ft. per second. A ferryboat moving slowly has great momentum, as is shown when it strikes the side of the slip. Why?

46. Force may be defined as that which tends to produce, to change, or to destroy the motion of a body, that is, to change its momentum. Forces may be measured by the velocities imparted in the unit of time, to the masses upon which they act; hence the equation for a force is

$$\text{Force} = \text{Mass} \times \text{Acceleration},$$

or

$$F = Ma, \qquad (14)$$

or, since $v = at$,

$$Ft = Mv.$$

47. The Absolute Unit of Force, in the C. G. S. system, is the *dyne.* This is the force that, acting upon 1 g. of mass, will give to it an acceleration of 1 cm. per second per second.

Since the dyne is a very small unit, it is sometimes convenient to use, instead, the *megadyne,* equal to 1,000,000 dynes.

In the F. P. S. system the absolute unit of force is the *poundal,* which is the force that by pushing against 1 lb. of matter will give to it an acceleration of 1 ft. per second per second.

The formula $F = Ma$ refers to absolute units; it means

$$\left\{\begin{array}{l}\text{No. of abso-}\\ \text{lute units of}\\ \text{force}\end{array}\right\} = \left\{\begin{array}{l}\text{No. of units}\\ \text{of mass (g.}\\ \text{or lb.)}\end{array}\right\} \times \left\{\begin{array}{l}\text{No. of units of length}\\ \text{in acceleration per sec.}\\ \text{per sec. (cm. or ft.)}\end{array}\right\}.$$

For instance, to measure a force that gives to a mass of 6 g. an acceleration of 5 cm. per second per second, we write $F = Ma = 6 \times 5 = 30$ dynes. Again, to determine the weight of a 1-pound mass at New York, or the force by which a mass of 1 pound is pulled downward by gravity there, we observe that a freely falling body at New York has an acceleration of 980.2 cm. or 32.16 ft. per second per second. Hence in this case $F = 1 \times 32.16 = 32.16$ poundals.

Since the dyne gives to one gram of matter an acceleration of 1 cm. per second per second and gravity acting on this same gram gives it an acceleration of 980.2 cm., the weight of 1 gram = 980.2 dynes. The force of gravity varies a little at different points on the earth's surface. But if we let g represent the acceleration due to gravity, and W the weight *expressed in absolute units of force*, the formula

$$\mathrm{W} = Mg, \text{ or } M = \frac{W}{g}, \tag{15}$$

will hold true for any place whatever.

48. The Gravity Unit of Force. — Instead of using absolute units, we may measure forces by comparing them with the weight of a standard mass. A force of 1 pound, for instance, means a force equal to the force by which a mass of 1 pound is pulled downward by gravity. The pound, as a gravity unit of force, is therefore equal, at New York, to 32.16 poundals; and the gram to 980.2 dynes. As the force of gravity varies at different places, the gravity unit of force

is variable. The pound, however, everywhere equals g poundals, and the gram everywhere equals g dynes.

By combining Equations 14 and 15 we obtain the formula

$$F = \frac{Wa}{g}, \qquad (16)$$

in which W is the weight of the body moved. If W is expressed in absolute units ($= Mg$), the result F will be expressed in absolute units; but if, as is usual, W is expressed in gravity units ($= M$), then F will be expressed in gravity units.

For instance, to measure the force that will be required at New York to impart in one second a velocity of 20 feet per second to a mass of 160 pounds, we write

$$F = \frac{Wa}{g} = \frac{160 \times 20}{32.16} = 99.5 + \text{pounds.}$$

49. Newton's Laws of Motion. — As a result of his investigation in mechanics, Sir Isaac Newton formulated the following laws:

I. *Every body tends to persevere in its state of rest or of uniform motion in a straight line, unless it is acted on by an impressed force.*

II. *Change of momentum is proportional to the impressed force and takes place in the direction of the straight line in which the force acts.*

III. *To every action there is always an equal and contrary reaction.*

50. Newton's First Law. — If a body is left in a certain place, and after an interval it is not found there, we understand at once that it has been removed, that some force has been brought to bear upon it. If, however, a body is in

motion, we cannot prove by actual experiment that it tends to go on in the same straight line, as the law states, because it is not possible to remove all resistances to a moving body, and these resistances are forces. But if the resistances are made as little as possible, the motion continues much longer. If a ball is rolled first on the ground, then on a floor, and then on smooth ice, with the same force each time, the effect of the reduced resistance is each time shown in the increased distance to which the ball rolls.

51. Newton's Second Law means that any force acting upon a body produces its own effect, whether acting alone or in conjunction with other forces.

This does not mean that if a motor boat, for example, starts directly across a river, it will land at the same point as it would if there were no current, but it does mean that the work done by the motor will carry the boat across the stream just as though there were no current flowing.

Fig. 18

52. Verification of Newton's Second Law. — When a body is dropped, it falls in a vertical line with a uniformly increasing velocity due to the constant force of gravity. If instead of being dropped it is struck a blow, it moves in a curved path, the resultant of the uniform motion due to the blow and the accelerated motion due to gravity. According to Newton's Second Law, the time of falling should be the same in both cases if the blow is given horizontally.

Demonstration. — A simple form of apparatus for the demonstration of this law is shown in Fig. 18.

A support carries near the top a shelf with a hole in it. A thin wooden strip, fixed at the upper end, comes vertically down above the hole in the shelf. Place a small ball or marble on each side of the strip, so that the one over the hole is suspended by pressure between the wooden strip and a cleat on the shelf. Let the hammer fall upon the strip, and one ball will be thrown out horizontally and the other dropped vertically.

53. Newton's Third Law is only a statement of what we are familiar with, as *reaction*. If a cup is struck against the edge of a table, the table reacts against the cup and breaks it. An ocean steamship is pushed along by the reaction of water against the blades of the screw propeller. If a swimmer attempts to dive from a springboard, he makes use of both the elasticity and the reaction of the board. In order to jump far a boy must stand on something fixed, so that it shall react against the push of his muscles. If he should attempt a long jump while standing upon the seat of a swing, he would only succeed in setting the swing in motion and getting a fall.

Demonstration. — The action and reaction of elastic balls can be shown by means of a grooved board. Place a single ball in the groove and then drive a second ball against it with the end of a stick. The moving ball will stop as soon as it strikes the one that is standing still, while that one will move on with the velocity of the first. Why?

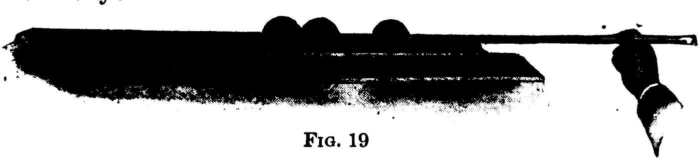


FIG. 19

With a half dozen balls, a number of combinations of stationary and moving balls may be made that will be helpful in understanding the significance of this law (Fig. 19).

The "Oscillator" electric fan is an example of the practical use of reaction. In this fan a circular disk is carried at the end of a rod which is so pivoted to the support of the fan that the disk can be swung from one side of the fan to the other. When the disk is on one side, as shown, the reaction of the air upon the blades of the fan is partly counterbalanced by the blowing of the current of air upon the disk. The reaction on the other side of the fan, not being counterbalanced, pushes the blades on that side backward, and the fan support turns on a vertical axis carried by the standard. When the fan has moved a certain distance, a pin connected with the disk rod strikes a stop placed on the base, and the disk is swung to the other side of the fan. The turning of the fan is now reversed, and it moves around until the projecting pin strikes a second stop, when a reversal again takes place. In this way an automatic distribution of the air current over a room is secured.

Fig. 20. — Oscillator Fan

54. Graphical Representation of Forces. — If the motion of a body is that imparted by a single force, its path will be rectilinear, and may be represented by a straight line. The elements of a force are: (*a*) its point of application; (*b*) its direction; (*c*) its magnitude. The force may be represented by a line beginning at the point of application, and extending in the direction in which the force acts, to a distance which is a measure of its magnitude. This means that all lines representing magnitudes must be drawn to the same scale.

The direction of the motion of a body or of the action of a force is indicated by placing on the line the point of an arrow. Such lines are called *vector lines*, or *vectors*.

55. Composition of Forces. — When two forces, having the same point of application, act at the same time upon

a body, we can imagine some one force, called the *resultant*, that would have the same effect as the two actual forces, which are called *components*. The direction and intensity of this resultant force may be found as follows:

(*a*) *When the forces act in the same direction.* — Suppose two forces act upon a body, tending to move it toward the east. Let one of them be a force of 2 dynes and the other of 3 dynes. Select a point A as the position of the

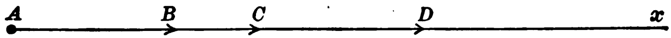


FIG. 21

body. Draw a line Ax (Fig. 21) to represent the direction in which the forces act. Take any convenient scale and lay off AB to represent 2 dynes, and AC to represent 3 dynes. Since the forces AB and AC are acting upon the same body at A and along the same line, Ax, and since each force produces its own effect, their resultant must be equal to the sum of AB and AC; hence it will be the force AD, representing 5 dynes.

The resultant of two forces acting in the same straight line, in the same direction, is the sum of the given forces.

(*b*) *When the forces act in opposite directions.* — Suppose the two forces to act, one toward the east and the other

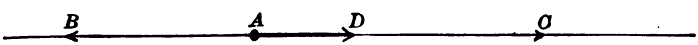


FIG. 22

toward the west, as in Fig. 22. It is evident that the force AB will act against AC, and that the resultant will be AD, their difference.

The resultant of two forces acting in the same straight line, but in opposite directions, is the difference of the given forces and acts in the direction of the greater. It two *equal* forces

act upon a body in opposite directions, their resultant will be zero, the forces will be in *equilibrium,* and the body will be at rest.

(*c*) *When the forces act at an angle to each other.* — THE PARALLELOGRAM OF FORCES. — (1) Suppose the force P (Fig. 23), of 3 dynes, to act toward the east, at a right angle to the force Q, of 2 dynes, acting toward the south. Represent P by AC, and Q by AB. Complete the parallelogram by drawing the dotted lines BD and CD (parallel to AC and AB, respectively), and their intersection will locate the point D and determine both the magnitude and the direction of the resultant, AD. For D is the only point that is as far east as C and as far south as B.

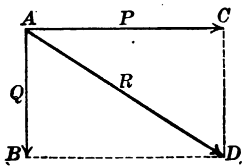


FIG. 23

In each figure all lines representing forces must be measured by the same scale.

(2) Suppose the force Q to act at an angle CAB to the force P (Fig. 24). Complete the parallelogram to determine the point D. Then, for reasons similar to the above, AD or R will be the resultant required.

The resultant of any two forces acting at an angle to each other may be found by completing the parallelogram upon the forces as sides and drawing the diagonal from the common point of application.

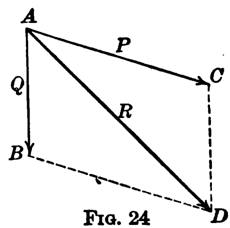


FIG. 24

(*d*) *When there are more than two forces.* — The resultant of any number of forces can be found by a repetition of the parallelogram of forces. Suppose three forces, P, Q, and S (Fig. 25), to be acting on a body at A. Complete the paral-

lelogram $ACDB$; then AD or R' will be the resultant of P and Q. Find the resultant of S and R' by completing the parallelogram $ADHE$; then AH or R will be the resultant of P, Q, and S.

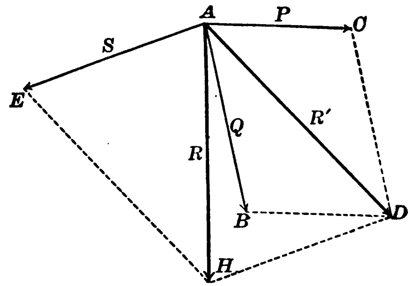


FIG. 25

56. Equilibrant. — The equilibrant of any number of forces is a force equal in magnitude, and opposite in direction, to their resultant. If the forces and their equilibrant act upon a body, the equilibrant will counteract the other forces, and the body will remain at rest. This condition is shown in Fig. 26, in which the equilibrant E and the forces P and Q keep the body A at rest.

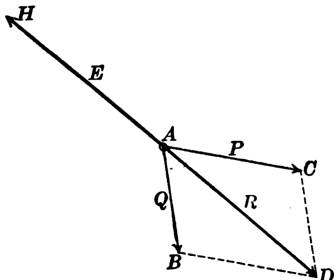


FIG. 26

57. Verification of the Parallelogram of Forces. — **Demonstration.** — A and B (Fig. 27) are two hooks at the top of a blackboard. To these attach two spring balances, C and D. Hook these to the ends of a cord to which a second cord is tied at H. Suspend a weight W from this cord, and the point H will be kept in equilibrium by the three forces. The resultant of the pulls exerted by the balances C and D may be found as follows. Mark the position of H

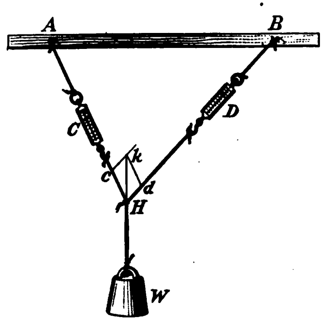


FIG. 27

on the blackboard and the direction of the lines leading to C and D. Take Hc to represent the reading of the balance C, and on the same scale lay off Hd to represent the reading of the balance D. Complete the parallelogram, and Hk, the resultant, will be found to represent an amount equal to W, the equilibrant, and to be vertical.

58. Forces not Lying in the Same Plane. — When three forces having the same point of application do not lie in the same plane, the resultant is the diagonal of the parallelopiped formed on these forces as edges. Suppose the three forces are P, Q, and S (Fig. 28). The resultant of P and Q is R' in the plane $ABEC$, while the diagonal AH is the resultant of R' and S in the plane $AEHD$, and is the required resultant.

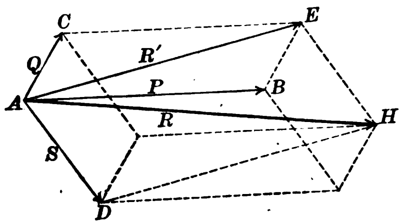


FIG. 28

59. Resolution of Forces. — In the composition of forces we have given the component forces to find the resultant, while in the resolution of forces the resultant is given and the components are to be found. When two components are to be found, the problem is to construct a parallelogram on the resultant as the diagonal, such that the desired components will be sides of the parallelogram. There are several cases of this problem, of which the following are the most important:

(*a*) Given, the resultant and one of two components, to find the other component (Fig. 29). Suppose the force P and one of its components Q are given, and it is required to find the

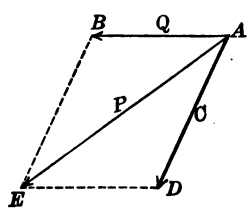


FIG. 29

other component. Complete the parallelogram on P as the diagonal and Q as one side (by connecting B and E, and drawing ED parallel to BA, and AD parallel to BE). Then C will be the required component.

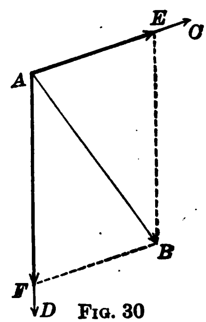


FIG. 30

(*b*) Given, the resultant and the direction of each of two components, to find the components. Let AB (Fig. 30) be the given resultant and AC and AD the directions of the required components. From B draw two lines, one parallel to AD and the other parallel to AC. Their intersections with AC and AD will determine the points E and F; and AE and AF will be the required components of AB.

60. General Condition of Equilibrium. — So far we have considered only motion of *translation*, or motion in which all the parts of the moving body move in the same direction and with the same speed. But there may also be a motion of *rotation*, as when a body turns on an axis. In rotation, parts of the body on opposite sides of the axis move at any instant in opposite directions; and each part moves continuously in a curved path, with a speed that varies with its distance from the axis. *In order to have complete equilibrium, not only must the resultant of all the forces tending to produce translation of the body be zero, but the resultant of all the forces tending to produce rotation must also be zero.*

61. The Moment of a Force. — Suppose there are two forces, F and F', acting at right angles to the bar AB, each tending to rotate it about the pivot C (Fig. 31). It is evident that the tendency of each force to produce rotation depends

not only upon the magnitude of the force, but also upon its distance from the point C, about which it tends to turn the bar. If the distance CA is d, and CB is d', the tendency to produce rotation exerted by F is proportional to the product Fd, which is called the *moment* of the force F; so, too, the moment of the force F' is $F'd'$. The point C, about which the rotation takes place, is called the *center of moments*. The force F' tends to produce a clockwise and the force F a counterclockwise rotation around the point C.

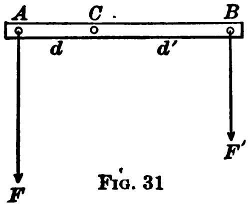


FIG. 31

If the forces F and F' do not act in a direction that is perpendicular to the bar AB, as in Fig. 32, then the distances d and d' will not be CA and CB, but CD and CE, which are the perpendiculars drawn from C to the directions of the forces.

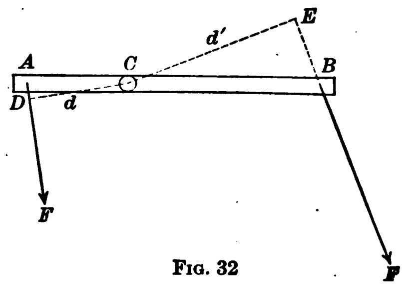


FIG. 32

The moment of a force is *the product of the force by the perpendicular distance from the center of moments to the direction of the force.*

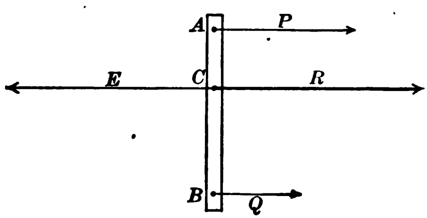


FIG. 33

62. Parallel Forces are two or more forces that act upon a body in parallel directions but at different points of application. Suppose two parallel forces, P and Q (Fig. 33), are acting

upon a rigid bar at the points A and B. Then the resultant, not only as regards translation but also with respect to rotation about any point in the bar, will be equal to the sum of the forces in magnitude, and parallel to them in direction, and will be applied at a point C, between A and B, such that $BC:AC = P:Q$. The equilibrant will also be applied at C, and is equal to R in magnitude and opposite to it in direction. This means that *whenever three parallel forces are in equilibrium, one of them is between the other two, is equal to their sum, and is opposite them in direction.* Since the moment of P equals the moment of Q, $P \times AC = Q \times BC$, from which the distance of C from either A or B can be found.

Demonstration. — The truth of the above equation for determining the point of application may be verified by suspending from a meter stick two weights, P and Q, and supporting the stick and its load by a spring balance or scale, as in Fig. 34. The weights can be supported from the meter stick by cords with loops passing over the stick, and the position of the scale can be found by slipping the loop to which it is attached along the stick until the stick balances in a horizontal direction. Before the proportion $P:Q = BC:AC$ is tested, a small weight should be suspended from the short end near A so that the stick will balance when the weights P and Q are removed. The scale will read not only the sum of P and Q, but the weight of the stick and small weight also.

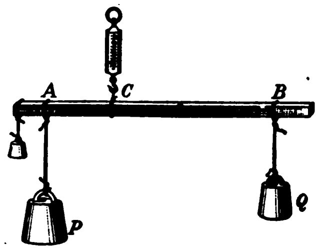


FIG. 34

The application of this principle is useful in determining the pressure upon the abutments of a bridge when a load is passing over it. If a train passes over the bridge, the pressures

upon the abutments (in addition to the weight of the bridge) are constantly varying from the whole weight to zero, and

FIG. 35. — Bridge across the Niagara River

vice versa, while the sum of the two pressures is equal to the weight of the train (Fig. 35).

The resultant of any number of parallel forces can be found by finding first the resultant of two of them, then combining this resultant with a third force to find their resultant, and so on. Any number of parallel forces are in equilibrium when the resultant of all the forces in one direction is equal to and has the same point of application as the resultant of all the forces in the opposite direction.

63. Couples. — The parallel forces P and Q shown in Fig. 33 can be replaced by a single force, R, or counterbalanced by a single force, E. Parallel forces, however, can be applied to a body in such a way that neither of these things can be done. If the parallel forces are equal and in opposite

directions, their resultant is zero so far as motion of translation is concerned, but they tend to turn the bar AB (Fig. 36) into the position shown by the dotted lines. This combination of forces is called a *couple* and produces rotation only.

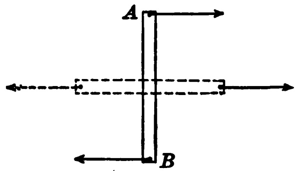


FIG. 36

64. The Graphical Representation and Composition of Velocities. — Any velocity of which the starting point, the rate, and the direction are known can be represented graphically by a vector line (§ 54).

If the directions of two component velocities are in the same straight line, the resultant velocity is either the sum or the difference of the two velocities. A person walking through a railway train from the rear to the front has a greater velocity with respect to the earth than a person sitting in a seat, while a person walking from the front to the rear has a smaller velocity.

If the directions of two component velocities are not in one straight line, the resultant velocity can be found by combining the velocities as forces are combined in the parallelogram of forces. For example, if a man rows a boat across a stream with a uniform velocity of 2 miles per hour while the stream flows with a uniform velocity of 1.5 miles per hour, the direction taken by the boat will be determined by these velocities independently of the width of the stream. If the boat starts from A,

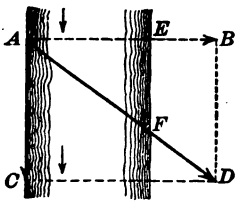


FIG. 37

Fig. 37, the direction of the path will be found by laying off AB to represent the velocity of 2 miles per hour and

AC at a right angle to it to represent a velocity of 1.5 miles per hour; then *AD* will be the direction the boat will take. If the width, *AE*, of the stream is known, the length of the path, *AF*, is easily determined.

A velocity, as well as a force, can also be resolved into components, as in § 59.

65. Reflected Motion. — If an elastic ball strikes against a fixed body, it will rebound. This is called *reflected motion*, and is caused by the reaction of the body against which it strikes. If a moving body is not elastic, the reaction of the body against which it strikes will flatten it, as, for example, when a ball of putty is dropped upon the floor. If both the bodies are highly elastic, the direction of the rebound will be such that *the angle of reflection will equal the angle of incidence*. This is the *Law of Reflection*, and may be verified as follows:

FIG. 38

Demonstration. — Place a strip of board on its edge upon a table resting against the wall. Roll an elastic ball across the table along the line *AB* (Fig. 38) against the board. From *B*, where the ball strikes, draw *BD* perpendicular to the board. Then the angle *CBD*, the angle of reflection, will be found equal to the angle *ABD*, the angle of incidence. (The path of the ball can be readily traced by dusting the table with crayon dust.)

66. Curvilinear Motion. — The path of a body whose motion is that imparted by a single impulsive force is rectilinear. If its motion is due to two impulsive forces that have acted upon it, its path will still be rectilinear; but if

the motion due to an impulsive force is combined with that due to a constant force, not acting in the same straight line, its path will be *curvilinear.* If a stone is tied to a cord and swung around, a curved path is the result. If the cord should break, the stone would go off in a straight line — the tangent line AB (Fig. 39); but the cord prevents the stone from taking such a course and compels it to go in the curved path ADE.

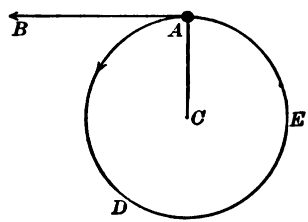


Fig. 39

67. Centripetal and Centrifugal Forces. — The pull of the string that compels the body in Fig. 39 to move in a circular path is directed toward the center, C, and is called the *centripetal force.* Since this force acts constantly in a direction at a right angle to the direction of the motion of the body, it does not affect its velocity, but does give it an acceleration towards the center. The reaction that the moving body offers to the centripetal pull of the cord is called the *centrifugal force* and is equal, in amount, to the centripetal force. If part of the cord is replaced by a spring scale, its reading will be a measure of this force, which depends upon the mass of the body, its velocity, and the radius of the circle.

The acceleration given by centripetal force is equal to $\frac{v^2}{r}$. Since force equals Ma or $\frac{Wa}{g}$, the expression for either centripetal or centrifugal force is

$$F_c = \frac{Mv^2}{r}, \qquad [1] (17)$$

or

$$F_c = \frac{Wv^2}{gr}. \qquad (18)$$

[1] For proof of this formula see Appendix.

Equation 17 expresses the force in absolute units, and Equation 18 in gravity units.

68. Examples of Centrifugal Force. — There are many examples of the so-called centrifugal force. In every case in which the force that holds the body to the center is overcome, the body flies off in a direction tangent to the curve. The flying of mud from a carriage wheel, the bursting of a grindstone, the separation of the milk from the cream in a dairy separator, the extraction of honey from the comb in a rotating extractor, the action of the water in a centrifugal drying machine, are all results of this force. It is on account of this tendency that a race course is banked to make the outside of the track the highest, and that on a curve of a railroad track the outer rail is made higher than the inner rail.

Fig. 40. — Centrifugal Extractor

Fig. 41. — Extractor Basket

In the governor of a steam engine two weighted arms hinged to a vertical shaft fly apart when revolving at high

speed and fall together at low speed. These motions control the admission of steam and hence the speed of the engine. The centrifugal drying machine or extractor (Fig. 40) used in laundries consists of an inner copper basket that can be rotated on a vertical axis at high speed. This basket (Fig. 41) is pierced with rows of holes along its circumference through which the water from the clothes is driven by centrifugal force.

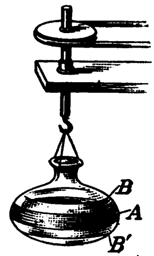


FIG. 42

Demonstration. — Attach to a rotating machine a flattened glass globe, suspending it as in Fig. 42. Pour into the globe some mercury and colored water. Put the machine in motion, and the mercury will form a ring around the globe at its greatest diameter, as at *A*, while the water will form a second ring inside, between *B* and *B′*.

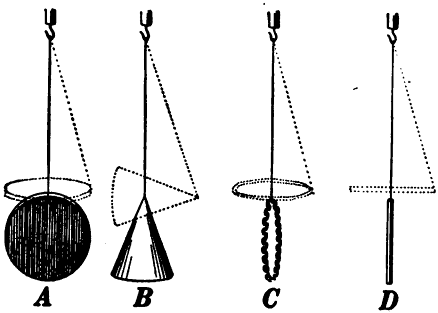


FIG. 43

Replace the globe by the objects that are shown in Fig. 43. *A* is a wooden disk suspended from the edge; *B*, a wooden cone suspended from the apex; *C*, a loop of small chain; and *D*, a rod suspended from one end. On rotating the support they will all tend to rotate on their short axes.

69. The Gyroscope. — The centrifugal force of a rotating body gives it great stability of position. This is shown by the action of an ordinary top, or better by a gyroscope — a wheel with a heavy rim rotating on an axle, the ends of which are pivoted in a ring. When this wheel is rotating at a high speed, it shows a strong re-


FIG. 44. — A Simple Gyroscope

sistance to any force that would change its plane of rotation or the direction of its axis.[1] Advantage is taken of this gyroscopic action in the placing of the flywheels of engines used on shipboard: they are so located that their axes extend crosswise of the ship, thus tending to reduce the sidewise rolling motion. In a Brennan one-rail car (Fig. 45), stability is secured by means of a pair of gyroscopic wheels rotating in opposite directions, with their axes extending across the car.

FIG. 45. — Brennan One-rail Car

By courtesy of *The Book of Knowledge.*

Questions

1. If a constant force acts upon a body at rest and gives it a velocity of 10 ft. per second in 5 sec., what is the average velocity of the body? What is its acceleration? How far would it move in the next 5 sec. if it neither gained nor lost velocity?

2. Suppose an automobile to start from rest and gain a velocity of 20 ft. per second in 4 sec. What was the acceleration?

3. Why does a loaded auto truck start more slowly than an empty one?

4. What would be the result of doubling the power of the engine of the truck?

5. Suppose both the load and power of the engine were doubled. What effect would it have upon the acceleration? Why?

---

[1] If the axle is supported at one end only, the force of gravity tends to depress the other end; but the gyroscopic resistance to this force produces, instead, a slow rotation of the entire instrument about the point of support, *with a nearly constant inclination of the axis to a horizontal plane.*

6. Why does the truck not stop as soon as the power is shut off? What means are employed to stop it?

7. Does the water pouring over a high fall reach the ground as soon as a stone dropped from the top?

8. Why does it require a harder pull to draw a loaded sled up a hill than along a level?

9. Suppose two boys pull on a rope attached to the hook of a spring scale, the ring of which is fastened to a hook in the wall. What will the scale read if one boy pulls 8 lb. and the other 12 lb.?

10. Suppose they tie one rope to the hook of the scale and another to the ring and pull in opposite directions, one pulling exactly 8 lb. as in problem 9, and the other pulling, or trying to pull, 12 lb. Will the scale move and what will it read?

11. What must each boy pull so that the scale will not move? How much will it then read? What will be the strain upon the ropes?

12. Suppose you had an old horse and a young horse hitched to a load. How would you hitch them to the evener so that the young horse would have to pull the greater part of the load?

13. How would you hitch three horses to an evener so that each must pull the same amount?

14. Why is a greater pull required at A, Fig. 31, than at B to keep the bar in place?

Problems

1. In a four-mile race between the Yale and Harvard crews, the time of the winning crew was 21 min. and 10 sec. What was the average speed in miles per hour? In feet per second?

2. At 6 o'clock on June 29, 1907, a 24-hour run was finished by a six-cylinder Napier motor car, at Weybridge, England. The distance covered was 1581 miles and 1310 yards. What was the speed in miles per hour and in feet per second?

3. If the motor car in problem 2 weighed 3600 lb., how would its average momentum compare with that of a freight car weighing 30,000 lb. moving at the rate of 16 mi. per hour?

4. Suppose a body to fall from a captive balloon and to strike the earth in 5 sec. Find its velocity on striking, the entire space passed over, and the space passed over in the last second. (Take $g = 32.16$ ft.; make no allowance for the resistance of the air.)

5. Suppose the body to be thrown vertically downward from a balloon with a velocity of 40 ft. per second, and to strike the earth in 5 sec. Find v, S, and s, as before.

6. Suppose a body to be thrown horizontally from a captive balloon with a velocity of 80 ft. per second and to strike the earth in 5 sec. Construct the curve of the path it will take.

7. A rifle was fired in a horizontal direction with a velocity of 900 ft. per second, from the top of a vertical cliff 100.5 ft. high, standing on the seashore. How far from the base of the cliff did the ball strike?

8. A baseball was thrown over a flagpole 30.63 m. high, just clearing it at the very top of its path. How long after it was thrown did it strike the ground? What was the vertical component of its velocity? Does it make any difference how far from the pole the ball is thrown? Explain the reason for your answer.

9. A rifle ball has a velocity, the horizontal component of which is 1028 ft. per second when it is fired at such an elevation that its range is 3084 ft. What is the greatest height the ball reaches?

10. The acceleration of a ball rolling down an inclined plane is 3 ft. per second per second. How long must the plane be if it takes 4 sec. for the ball to roll to the bottom? What is its final velocity?

11. A stone dropped from a bridge strikes the water in 3.5 seconds. How high is the bridge?

12. A certain block of marble weighs 6 kg. at New York on a spring scale. To how many dynes is this weight equal?

13. Three ropes are fastened to a ring. A boy pulls on the first rope to the east with a pull of 40 lb., another to the south with a pull of 60 lb., and a man pulls the third rope in such a direction and with such a force as to keep the ring stationary. How much must the man pull and in what direction? Find the direction by the graphical method.

14. A sailor, on a ship that is sailing at the rate of 10 mi. per hour, climbs from the deck to a point on the rigging 50 ft. above in half a minute. Show by a figure the path he takes through the air, and compute its length.

15. A trolley car going north at the rate of 16 mi. per hour meets an east wind having a velocity of 30 ft. per second. From what

direction does the wind seem to come, and what velocity does it seem to have?

16. A weight of 300 lb. is suspended from a pole resting on the shoulders of two men. If one man carries three fifths of the load, and is 4 ft. from the weight, how far is the other man from it?

17. Two parallel forces, one of 36 lb. and one of 64 lb., act on one side of a wooden bar at a distance of 9 ft. from each other. Where must a third parallel force be applied to keep the bar in equilibrium? How great a force must it be and in what direction must it act?

18. A weight of 32 lb. is suspended from a hook at A, by a cord AB. A second cord is tied at B and this is pulled horizontally in the direction BC until the cord AB makes an angle of 30° with its original vertical position. Find the pull on BC and the tension on A. Solve graphically. Suspend any weight, attach the hook of a spring balance at B, and prove experimentally.

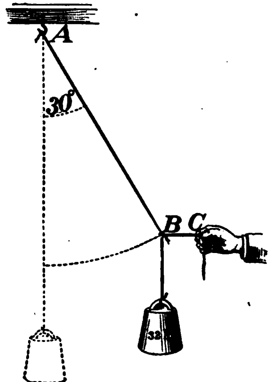


FIG. 46

19. An ocean steamer is going northeast at the rate of 400 mi. per day (24 hr.). How far north is she going per hour? How far east?

20. A balloon rises with a vertical velocity of 138 ft. per minute, while the wind causes it to take a path making an angle of 60° with the ground. What is the horizontal velocity of the wind? What is the speed of the balloon? Solve graphically.

21. Three boys carry a boat that weighs 250 lb. The center of gravity or point of application of the weight of the boat is 8 ft. from the stern. One boy lifts from the stern and the other two from a cross stick placed underneath the boat. How far from the center of gravity must the cross stick be placed if each boy lifts the same amount? How far must it be if the two boys carry three fourths of the boat?

22. At New York a ball weighing 9 lb. is swinging around a circle 5 ft. in diameter with a velocity of 22 ft. per second. What pull must be used to keep the ball in its path?

II. ENERGY AND WORK

70. Energy. — The head of a pile driver (Fig. 47) falling upon a pile forces the pile into the ground to a depth which depends upon the weight of the head and the height from which it falls. Increase either, and its capacity for doing work, that is, its energy, is increased, and the pile is driven farther into the ground. If we watch the engine of a pile driver while it is pulling the iron head to the top of the frame, we shall see that it is doing work. When the head has been raised and is held in position, the work of the engine stops, but the steam pressure is still there ready to be used at short notice.

FIG. 47. — Pile Driver

Steam under pressure is said to possess *energy*. Energy may be defined as the *capacity for doing work*. It is measured by the amount of work it is capable of doing.

71. Potential Energy. — We have only to loosen the catch which holds the head in place to find that the head also is ready to do work. When the catch is loosened, the head falls, strikes upon the top of the pile, and its capacity for doing work is shown by driving the pile into the ground. If the

head is again raised, but only half as high, it will be found on dropping it that but half as much work is done. This shows that the height from which the head falls must be taken into account, as well as the weight of the head itself.

The energy that a body has on account of its position is called *potential energy.* The work that has been done on a body to place it in a certain position is the measure of its potential energy. This measure is expressed by the equation

$$P.E. = Wh, \tag{19}$$

in which W is the weight of the body and h is its vertical height above the point with reference to which its potential energy is measured. Energy is measured in the same units as work. For instance, the potential energy of a 10-lb. weight ready to fall 6 ft. is 60 *foot pounds.*

72. Kinetic Energy. — When the head strikes the pile, the work that had been stored up as potential energy in raising the head to its position of rest becomes available on account of the velocity acquired in the fall. This form of energy which is dependent upon the velocity of a body is called *kinetic energy.* The work that has been done on a body to give it a certain velocity is a measure of its kinetic energy. We have already learned that work = force × distance, and that force (in absolute units) = mass × acceleration; hence we may write as an expression of kinetic energy,

$$K.E. = FS = MaS.$$

But (Formula 4) $S = \frac{1}{2}at^2$; hence $K.E. = \frac{1}{2}Ma^2t^2$, and since $v = at$ (Formula 3),

$$K.E. = \frac{1}{2}Mv^2, \tag{20}$$

in which v is the velocity per second, and $K.E.$ is expressed in absolute units.

If $K.E.$ is to be expressed in gravity units,

$$K.E. = FS = \frac{WaS}{g}\text{; whence } K.E. = \frac{Wv^2}{2g}. \qquad (21)$$

Since g (at New York) is 32.16 ft., the formula may be written

$$K.E. = \frac{Wv^2}{64.32},$$

when the weight is given in pounds, the velocity per second in feet, and the result is required in foot pounds.

73. The Transformation of Energy. — The pendulum affords a ready means of showing that potential energy may be changed into kinetic, and *vice versa*. Let a ball A be suspended by a cord from a fixed point P (Fig. 48). The ball when at rest will take the position A, where, since it is at rest at its lowest point, it has neither potential nor kinetic energy. In order to move it to B, work must be done on it equivalent to raising it through the vertical distance DB. At B it has potential energy only, and if it is allowed to swing, it will move down the arc, losing potential energy and gaining kinetic, until it reaches A, when its energy will all be kinetic and will be sufficient to carry it up the other branch of the arc to the point C, a distance CE above the horizontal line, practically equal to DB; and here its energy is again all potential. If a spiral spring, the spring for a screen door, for example, is used as the suspending cord, and a kilogram weight for the pendulum bob, a further transformation takes place, the to-and-fro vibration changing into a vertical vibration and then back again repeatedly.

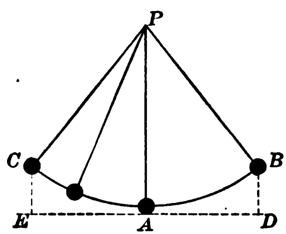


FIG. 48

The kinetic energy of the pendulum is employed in raising it against the force of gravity and restoring its potential energy. The case of a rifle ball striking against a stone wall is somewhat different. The motion of the ball is stopped and its kinetic energy is transformed chiefly into mechanical work and heat, for the ball itself is shattered, the wall is defaced, and if the velocity is very great, heat enough is produced to melt part of the ball.

The potential energy stored in coal may be transformed into heat energy by combustion, this into kinetic energy, if applied to a boiler and steam engine, and this into electrical energy, if the engine is used to turn a dynamo.

74. The Conservation of Energy. — When a ball is fired from a rifle, none of the energy that is developed by the combustion of the powder is lost, but it is all transformed into other forms of energy. Both the rifle and the ball are put in motion, producing kinetic energy; the air is thrown into vibration, producing sound; the ether is thrown into vibration, producing light; and to these results must be added the heat of the combustion. The sum of all these forms of energy is equal to the potential energy of the powder, and there is no loss.

By extending the consideration to all kinds of transformation of energy, scientists have reached the conclusion that *energy can neither be created nor destroyed,* and hence that *the total amount of energy in the universe is constant.*

The pile driver is a good example of both the transformation and the conservation of energy. As the head rises from the top of the pile the work of the engine gives it potential energy. The measure of this is the amount of work it is capable of doing. This is changed into kinetic energy as

the head falls, and when it strikes the top of the pile it delivers the same amount of kinetic energy that it had of potential energy when it started. That is, its kinetic energy equals its potential energy. A simple way to compute kinetic energy is to find how far the velocity of the moving body would carry it vertically upward and use that distance for h in the expression for potential energy.

75. Work. — Whenever a force acts upon a body in such a way as to move it, or to modify its motion, *work* is said to be done. However great the force used, no work is done unless the body is moved. A man going upstairs, a boy playing ball, and a crane lifting loads from one position to another (Fig. 49), are all doing work.

76. Measurements of Work. — The amount of work done varies directly as the force employed and the distance through which it acts. Hence the formula may be written

$$\text{Work} = FS. \tag{22}$$

There are four fundamental *units of work*, as follows, depending on the units in which F and S are expressed:

Absolute Units

I. *The erg* is the work done by a force of 1 dyne acting through a distance of 1 centimeter.

II. *The foot poundal* is the work done by a force of 1 poundal acting through a distance of 1 foot.

Gravity Units

III. *The kilogrammeter* is the work done in raising 1 kilogram 1 meter vertically against the force of gravity.

IV. *The foot pound* is the work done in raising 1 pound 1 foot vertically against the force of gravity.

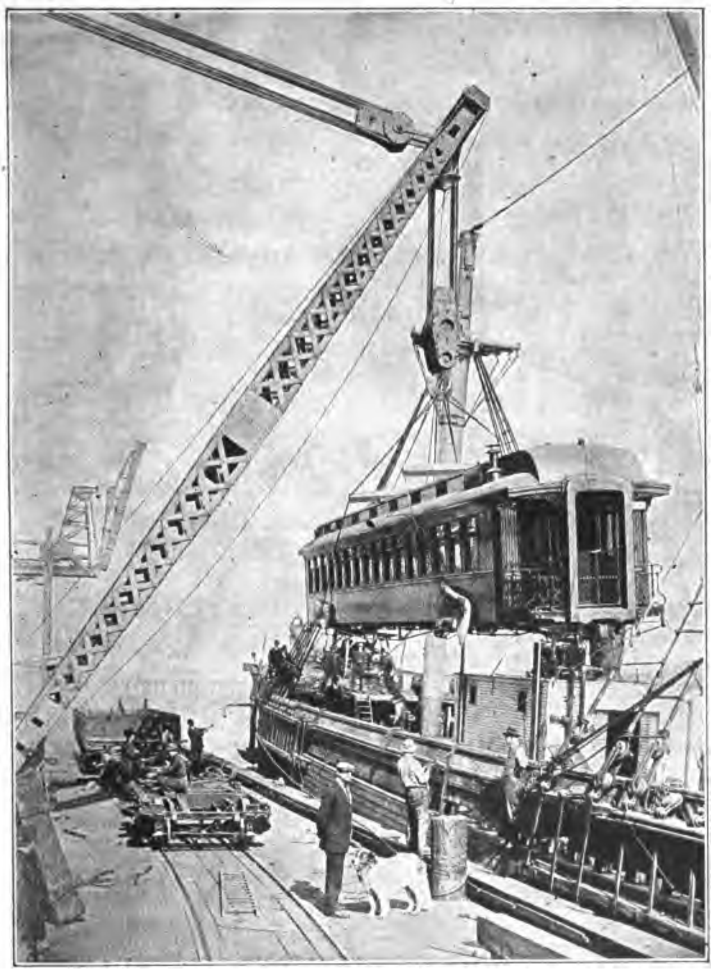


Fig. 49. — Loading of a Railroad Car on a Ship

This picture, made in Seattle, shows a railroad car being put on board for shipment to Alaska. By means of the crane it was lifted off its tracks, at the left, and is now being swung into position over the ship.

Other units of work may be used, depending upon the conditions. Since the erg is a very small unit, a larger unit, called the *joule*, is sometimes used; 1 joule = 10^7 ergs, or 10,000,000 ergs. The foot pound and the kilogrammeter are the units generally used in engineering work.

TABLE OF EQUIVALENTS AT NEW YORK

1 pound = 32.16 poundals.
1 foot pound = 32.16 foot poundals.
1 poundal = $\frac{1}{32.16}$ pound = $\frac{1}{2}$ oz. nearly.
1 gram = 980.2 dynes.
1 kilogrammeter = 98,020,000 ergs.
1 kilogrammeter = 7.233 foot pounds.

Formula 22 shows that if a man lifts a stone weighing 100 lb. $2\frac{1}{2}$ ft. high, the work done is $100 \times 2\frac{1}{2} = 250$ foot pounds, and that if an engine raises 12 kg. 20 m. high, the work done is $12 \times 20 = 240$ kilogrammeters.

77. Time is not an Element in Work. — Too great stress cannot be put upon the statement that the time employed in doing a certain amount of work has nothing whatever to do with the amount of work done. When 1 lb. is raised 1 ft., exactly 1 foot pound of work is done, no matter whether the time taken in the raising is 1 second or 1 hour or 40 hours. The dealer who pays a lump sum for the unloading of a boatload of coal, pays for that alone, and not for the time that may be consumed by the use of an imperfect hoisting machine.

78. Time; Rate of Work; Horse Power. — The work done in a given time, divided by the time, gives the average rate of doing work, or *power*.

The C. G. S. unit of power is the erg per second. In practical work the joule per second is used; this is called the

watt in honor of James Watt, the inventor of the steam engine.

$$1 \text{ watt} = 1 \text{ joule per second} = 10^7 \text{ ergs per second.}$$
$$1 \text{ kilowatt} = 1000 \text{ watts}$$

In the F. P. S. system the unit of power is the foot poundal per second. This is a small unit and is seldom used, the practical unit being the *horse power*, which means a rate of 33,000 foot pounds per minute, or 550 foot pounds per second;[1] hence the expression for horse power is

$$\text{No. H. P.} = \frac{\text{No. foot pounds}}{33000 \times \text{No. minutes}}. \qquad (23)$$

This unit was introduced by James Watt and its value was assigned by him. It is the work that would be done in one minute by a horse walking at the rate of three miles per hour and raising a weight of 125 pounds at the same rate by a rope passing over a pulley. One horse power is rated at 746 watts or 0.746 kilowatts. Hence the horse power is practically three fourths of a kilowatt and one kilowatt equals one and one third horse power.

The kilowatt is used to measure the power output of electric generators, while the steam power input, used in engines or turbines, is measured in horse power or myriawatts (1 myriawatt = 10 kilowatts).

[1] The relation between the horse power and the watt is determined as follows:

1 horse power = 550 foot pounds per second.
1 foot = 30.48 centimeters.
1 pound = 453.6 grams.
1 gram = 981 dynes. (The number varies with the value of g; this is about the value for the latitude of Paris.)

Hence 1 horse power = $550 \times 30.48 \times 453.6 \times 981 = 7{,}459{,}671{,}542$ ergs per second. Hence 1 horse power = 745.97 watts.

In New York, $g = 980.2$ dynes, hence one horse power = 745.36 watts.

Questions

1. Define work; energy; horse power; kilowatt. Illustrate each.

2. State the difference between potential and kinetic energy.

3. What is meant by conservation of energy? Transformation of energy? Give examples of the latter.

4. Can force be used without doing work? Give examples.

5. What element enters into rate of work or power, that does not enter into work?

6. A boy tosses a 2-lb. weight vertically upward with such a velocity that it rises for two seconds. What is its greatest kinetic energy? What is its greatest potential energy?

7. A 4-lb. weight was allowed to drop freely for 4 seconds. From what height did it fall? What energy did it acquire?

8. What is the kinetic energy of a 5-lb. mass having a velocity of 96 ft. per second?

9. How much work is done if a kilogram force acts upon a body and moves it 1500 cm.?

10. A 2-lb. ball falls for 2 sec. and rebounds a distance of 40 ft. How much mechanical energy has the ball lost? What has become of the lost energy?

11. A boy holds a 2-lb. stone in his hand. Is he doing any work? Does he do any work when he throws the stone? What kind of energy does he give to the stone?

12. A horse pulling a load uphill gives out when halfway up and is only able to keep the load from sliding back. Is he doing any work? Why?

13. If he were unable to keep the load from sliding back, would any work be done? If so, by what force?

14. What transformations of energy take place in the working of a locomotive?

Problems

1. How much work is done in drawing a sled 300 ft. if the force required is 24 lb.?

2. How much work is done in carrying a ton of coal (2240 lb.) up two flights of stairs, the total height being 21 ft.?

3. On attaching a spring scale to a block of wood and pulling it over a floor, the reading of the scale was found to be 16 kg. How much work was done in drawing the block over a distance of 22 m.?

4. A boy with his toboggan weighs 140 lb. He slides down a chute 150 ft. long in 2.5 seconds and has a velocity of 40 ft. per second at the bottom. What is his acceleration, and what kinetic energy does he have at the end of his trip?

5. How much work does a boy weighing 120 lb. do in walking upstairs to a height of 12 ft.?

6. A man weighing 186 lb. carries a package weighing 32 lb. upstairs from the first to the third floor of a building. How much work does he do if the vertical distance is 19 ft.? How much does he do upon himself? How much in carrying the package?

7. What horse power is required to raise 3.5 long tons (a long ton is 2240 lb.) from a mine 780 ft. deep in 1.5 minutes? What is the power of the engine in watts?

8. What is the potential energy of the head of a pile driver weighing 500 lb. when it is 28 ft. above the end of the pile? When it is 16 ft. above the end of the pile? If it is let fall from the height of 28 ft., it will strike the pile with a velocity of 42.438 ft. per second. What will be its kinetic energy on striking?

9. A quarry crane hoists a block of marble 6 ft. long, 4 ft. wide, and 2.5 ft. thick. How much work is done in raising the block 12 ft. if the marble weighs 160 lb. per cubic foot? Neglecting friction, what must be the horse power of the motor to do this in 3 min.? What is the potential energy of the block at that height?

10. How long will it take a 66-horse power engine to raise a weight of 299,000 lb. to a height of 300 ft.?

11. How many horse power must be developed by a locomotive when pulling a train 10 mi. per hour, the force required being 12,000 lb.?

12. An elevator weighing 1800 lb. more than its counterweight carries a load of 6 people of an average weight of 140 lb. each. Neglecting friction, what must be the horse power of a motor that will lift it 72 ft. in 30 sec.?

13. An ordinary brick weighs 5 lb. How long would it take to fall to the ground from the top of the Kodak Company's chimney in Rochester, which is 366 ft. high? With what velocity would it strike? What would be its kinetic energy on striking?

III. GRAVITATION AND GRAVITY

79. Law of Universal Gravitation. — Gravitation is the name given to the mutual attraction between different bodies of matter. The matter considered may be two books lying on a table, or two stars separated by millions of miles. The attraction is universal, and the *Law of Universal Gravitation* may be stated as follows:

Every particle of matter in the universe attracts every other particle with a force that varies directly as the product of the masses of the particles and inversely as the square of the distance between them. This leads to the formula which is applicable to all mutual attractions, namely,

$$F_g = \frac{Mm}{d^2}a, \tag{24}$$

in which a is the unit of attraction; *i.e.*, the attraction between two units of mass at a unit's distance.

For comparing two attractions of the same kind we may write the proportion

$$F_g : F'_g = \frac{Mm}{d^2} : \frac{M'm'}{(d')^2}.$$

The momenta given by mutual attraction to the two bodies between which the attraction acts, are equal. A man standing in a rowboat and pulling on a rope that is fast to a sloop moves the boat faster than the sloop, but only because its mass is much less. The momentum imparted to the sloop is equal to that given to the rowboat.

80. Gravity. — While the term *gravitation* is applied to the universal attraction existing between particles of matter, the more restricted term *gravity* is applied to the attraction that exists between the earth and bodies upon or near its

surface. The law given above applies to gravity, provided that d is measured in a straight line from the center of the earth to the center of mass of the body. This line is called a *vertical* line, or sometimes a *plumb* line (from the Latin word *plumbum,* which means "lead"), as vertical lines are frequently determined by suspending a mass of lead, the *plumb bob,* at the end of a cord (Fig. 50).

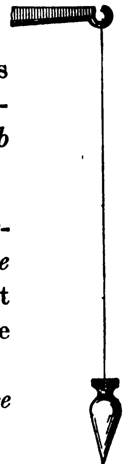


FIG. 50

81. Weight.—The weight of a body is *the measure of the mutual attraction that exists between the earth and that body.* This force is the resultant of the attractions between the earth and all the particles of the body.

The weights of any two bodies at the same place are proportional to their respective masses.

Since the polar diameter of the earth is $26\frac{1}{2}$ miles less than the equatorial, it is evident that the weight of a body will vary with the latitude as well as with the elevation above the sea level. The weight of a body carried from either pole toward the equator is decreased by the increase in its distance from the center. There is also an apparent decrease, owing to the increase in the centrifugal force of the earth's rotation. Bodies on the equator move with a velocity of more than a thousand miles per hour, and the centrifugal force there is $\frac{1}{289}$ of the force of gravity, while at the poles it is zero. Should the earth rotate 17 times as fast as it now does, the centrifugal force would equal the force of gravity, since centrifugal force varies as the square of the velocity (Formula 17).

82. Weight above the Surface. — *The maximum weight of a body is at the surface of the earth.* If a body is removed

above the sea level, as on the top of a mountain, or in a balloon, the distance d between it and the center of the earth is increased, and its weight is diminished. The relation between weight at the surface and weight above the surface may be expressed by the proportion

$$W : w = d^2 : D^2, \tag{25}$$

in which W is the weight at the surface; w, the weight above the surface; D, the distance from the center to the surface of the earth; and d, the distance of the body from the earth's center.

83. Center of Gravity. — The attraction of gravity on any body tends to draw its particles toward one point, and hence, strictly speaking, the directions of these forces are not parallel. As the radius of the earth is very large, however, compared with the size of any object which is weighed, their divergence from parallel lines is, practically, not measurable. The point of application of the resultant of all the parallel forces (§ 62) that make up the weight of a body is its *center of gravity*, *center of mass*, or *center of inertia*.

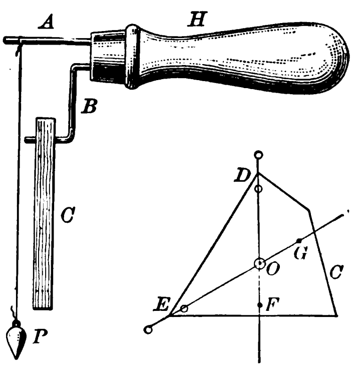


Fig. 51

Demonstration. — Fit in a small wooden handle (or in a fixed support), two wires (Fig. 51): one, A, straight and the other, B, bent twice at right angles. In a piece of thin board C of any shape bore holes D and E in two corners. Suspend the board by one of these holes D from the wire B, and from A suspend a plumb line. See that D is exactly halved by the plumb line when at rest, and mark a

point F opposite the line. Suspend the board from the hole E, and mark the point G. Draw lines DF and EG, and their intersection O will determine the center of gravity. Test the accuracy of the work, by making a hole at O and rotating on the end of A.

Find, in the same way, the centers of gravity of a triangle, a square, a rectangle, and a circle.

In the above cases the center of gravity is midway between the two surfaces at the point O. It would still be at O, if the thickness of the board were infinitely reduced; hence we may speak of the center of gravity of a surface. The center of gravity of any body may be found by suspending it successively from two points on the body and finding the intersection of the lines of direction from those points of support to the center of the earth. This is because a body suspended from any point will hang with its center of gravity vertically below the point of suspension. The center of gravity is frequently outside the substance of the body, as in the case of a ring.

84. The Center of Gravity of a Number of Bodies rigidly connected may be determined by considering the weight of each body as a parallel force applied at its center of gravity, and then finding the point of application of the resultant of these forces (§ 62). Suppose three parallel forces, P, Q, and S, to be applied at three points, A, B, and C, rigidly connected, as in Fig. 52.

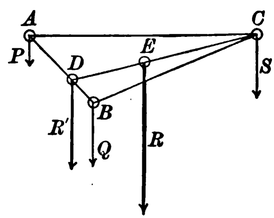


FIG. 52

The resultant R' of P and Q will equal $P + Q$, and its point of application will be at a point D, determined by the proportion (§ 62)

$$P : R' = DB : AB,$$

whence $$DB = \frac{AB \times P}{P + Q}.$$

Now connect D with C, and three forces P, Q, and S are replaced by the two forces S and R'. Find in the same way the point of application E of their resultant, and this will be the center of gravity of the system.

Demonstration. — Select a board of uniform thickness and put in it a screw hook close to each corner. Weigh the board, and determine its center of gravity by calculation. Suspend from each hook a known weight, as 2, 4, and 6 pounds, for example. Let each member of the class make a drawing of the board and locate on it the position of the center of gravity of the board and the position of each weight, and determine the center of gravity of the system by construction. When this has been done, put a screw eye in the upper side of the board at the point found, and lift the board and weights with a spring scale. Does the board hang horizontally? What is the weight of the system?

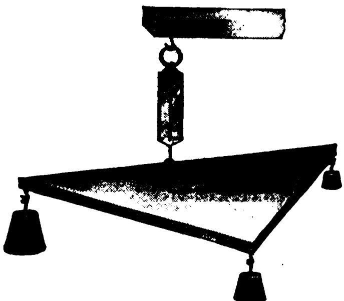


FIG. 53

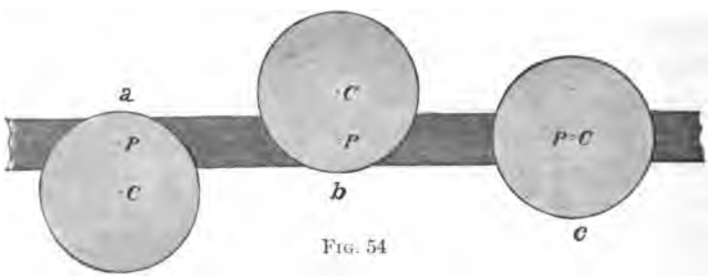


FIG. 54

85. Equilibrium. — Pierce a disk of cardboard with two holes, one at the center, and the other near the edge. Suspend it on a pin P (Fig. 54), from the hole near the edge

and it will take the position a, such that the center will lie in the vertical line below P. If the disk is moved, *the center of gravity will be raised*, and the disk will tend to return to its first position. This condition is that of *stable equilibrium.*

If the disk is placed in position b, and a slight push is given to it, *the center of gravity will be lowered;* and the disk will tend to go farther from its position. This is the condition of *unstable equilibrium.*

Place the disk in position c. Set it in motion, and *the center of gravity neither rises nor falls*, and the disk comes to rest in one position as well as another. This is the condition of *neutral equilibrium.*

86. Stability. — When a body is in a condition of stable equilibrium, (a) a vertical line from the center of gravity will either pass through the point of suspension, or fall within the base of support; and in order that a body may have great stability (b) the base must be large and (c) the center of gravity low. An ordinary pyramid fulfills these conditions. The center of gravity of a pyramid (Fig. 55, for example) is a point (C) on a line (GF) joining the vertex and the center of gravity of the base, and at a distance from the base equal to one fourth the length of the line (that is, $CF = \frac{1}{4}\, GF$).

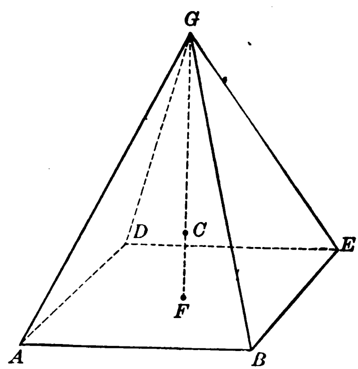


FIG. 55

The stability of an automobile is increased by having the

frame of the "underslung" type (Fig. 56), thus bringing the center of gravity near the ground.

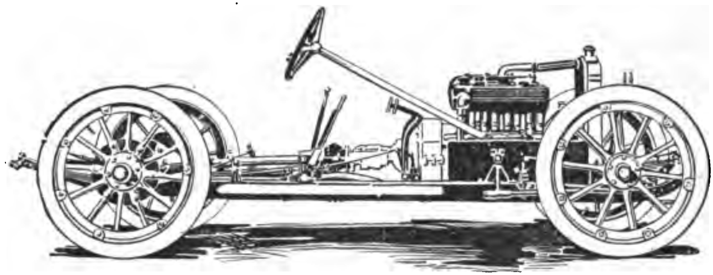


Fig. 56. — Underslung Automobile Chassis

87. Work Done in Overturning a Body. — The work that must be done to overturn a body is a measure of its stability. When a cylinder lies upon its side, the only work necessary to overturn it is to overcome the friction between it and the surface upon which it lies, since the center of gravity moves in a horizontal line. If, however, the body is a cube, the center of gravity is raised a distance *ab* every time it is turned over, and the work done is just the same as would be done in lifting the cube through the height *ab* (Fig. 57).

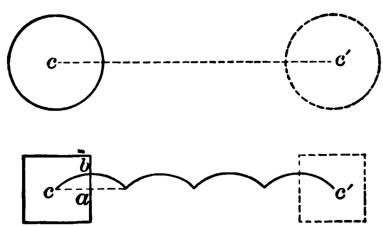


Fig. 57

A brick lying on a table upon its side has greater stability than one standing on end. The work necessary to overturn it in each case is expressed by the formula $Work = W \times ab$.

In both cases shown in Fig. 58 the highest position of the center of gravity is the same, but the original heights above

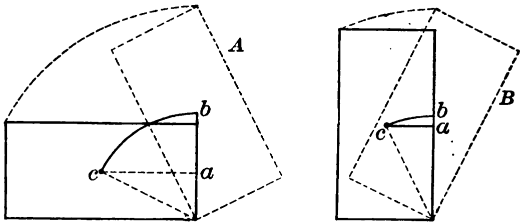


FIG. 58

the table are unequal and so the product $W \times ab$ is greater in A than in B.

Demonstration. — Get a brass ball such as is used on the ends of curtain poles. Remove the screw, enlarge the hole, and pour in a little melted lead. When the lead has cooled in position A, put the ball in any other position, as B, and since a vertical line from the center of gravity C does not fall within the base D, the ball will roll and the center of gravity will fall until it reaches the lowest possible position, when a vertical line from C will fall within the base of support, and the ball will be in a condition of stable equilibrium.

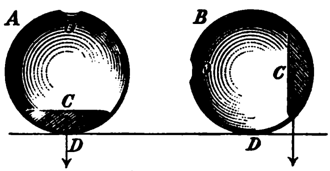


FIG. 59

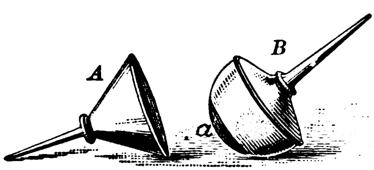


FIG. 60

The principle of this demonstration is applied in making one kind of oil cans. The ordinary form is conical (Fig. 60, A), and if it is overturned, the oil escapes. But when the base is made in the form of a hemisphere and loaded with a little lead in the

bottom (*a*), the can will always right itself and the oil will be retained.

Questions

1. Which is greater, the attraction of the earth for a pound of iron, or the attraction of the pound of iron for the earth?

2. What effect will it have upon the attraction between two bodies to increase the distance between them from 3 ft. to 6 ft.? To diminish it from 3 ft. to 1 ft.?

3. The distance of the sea level from the center of the earth decreases from the equator to the poles. What effect will this have upon the weight of a body taken from the equator toward either pole?

4. What effect will it have upon the mass of the body?

5. Where is the center of gravity of a baseball? Of a football? Of a tennis racket?

6. If you take a hammer by the handle and throw it into the air with a twisting motion, which will describe the larger circle, the handle or the head? Why?

7. In what position will a stick loaded at one end float in water? Why?

8. Which is the most stable body, a table with a marble top or one with a wooden top, other things being equal? Why?

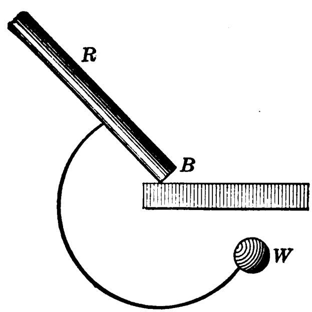


FIG. 61

9. A wooden rod *R* to which there is attached a wire bent into the form of a semicircle, and having a weight *W* attached at the other end, will, when supported on the end *B*, swing back and forth. Why?

10. A man standing with his back against a vertical wall cannot pick up anything from the floor in front of him without falling. Why?

11. Describe and explain the difference between the position of a man carrying a pail of water in one hand and a man carrying a pail of water in each hand.

Problems

1. Suppose three balls, weighing respectively 6, 10, and 18 lb., to be placed at the distances represented in Fig. 62. If the attraction (F_G on page 80) between A and B is 9, what will the attraction (F'_G) be between A and C? Between B and C?

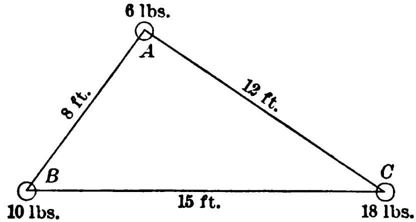


Fig. 62

2. The weight of a body at the surface of the earth is 125 lb. What would be its weight if it were 1000 mi. above the earth's surface? (Take 8000 miles as diameter of earth.)

3. Two iron balls, weighing 10 and 6 lb. respectively, are fastened to the ends of a rod, with a distance of 4 ft. between their centers. Assuming the rod to be without weight, where is the center of gravity of the system? Where is it if the connecting rod weighs 4 lb.?

4. A plank 12 ft. long, weighing 60 lb. is used by two boys for a seesaw. The boys weigh 80 lb. and 120 lb. respectively. Where is the center of gravity of the system if the boys sit at the very ends of the plank?

5. A beam 10 ft. long and weighing 300 lb. has a 200-lb. stone placed on one end. The beam with its load is then balanced on a log. How far from the stone must the log be placed?

6. A meter-stick weighing 100 g. has a kilogram weight suspended from one end. Find the center of gravity of the system.

7. A flagpole 100 ft. long is to be raised. It weighs 5 short tons and the center of gravity is 30 ft. from the base. How many foot pounds of work are required to raise it?

8. How much work is required to turn over a marble cube 4 ft. on the edge if the marble weighs 160 lb. per cu. ft.?

IV. THE PENDULUM

88. Simple Pendulum. — The ideal simple pendulum is one in which a heavy material particle is hung from a fixed point with a weightless cord. It is impossible to make such

a pendulum, but we get nearly the required conditions by suspending a small ball by a light thread.

89. Motion of a Pendulum. — Whenever a pendulum, as OA (Fig. 63), is moved out of its position of rest to any other position, as OB, it will, on being released, go back to A and, owing to the kinetic energy developed by its fall, go on to the position C, AC being slightly less than AB. A to-and-fro movement once over its path and back is called an *oscillation*, or vibration; and the distance that A moves from its position of rest — AB or AC — is the *amplitude* of the oscillation. In order to find the force that causes the pendulum to move over this path, we must find two components of the force of gravity BD, one, BE, which produces a pressure on the point of suspension O, without producing any motion, and the other, BF, which acts at a right angle to BE and is the force required. The magnitude of this force is that fraction of the weight of the pendulum represented by $\frac{BF}{BD}$.[1] This force varies from zero at A to the weight of the pendulum at a point on a level with O. Since in ordinary pendulums the amplitude is never large, the moving force is always a small part of this weight.

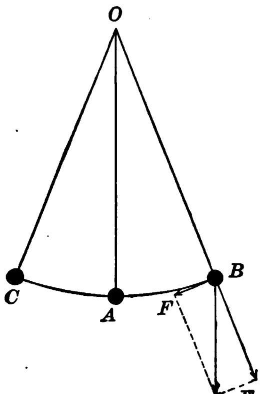


Fig. 63

[1] The value of the fraction can be obtained graphically by measuring BF to the same scale as BD.

90. Laws of the Pendulum. — **Demonstration.** — Suspend side by side four pendulums made by fastening lead balls to the ends of strong threads (Fig. 64). Make two of them 1 m. long, one 50 cm., and one 25 cm. Measure the distance from the point of suspension to the middle of each ball. Vibrate pendulums *A* and *B*. Do two pendulums of the same length vibrate in the same time? Vibrate *A* and *B* so that one swings about twice as far as the other. Do they still vibrate in the same time? Vibrate *B* (or *A*) and *C*. Does a pendulum half as long as another vibrate in half the time? Vibrate *B* (or *A*) and *D*. What is the relation between the time of vibration of one pendulum and that of another one fourth its length?

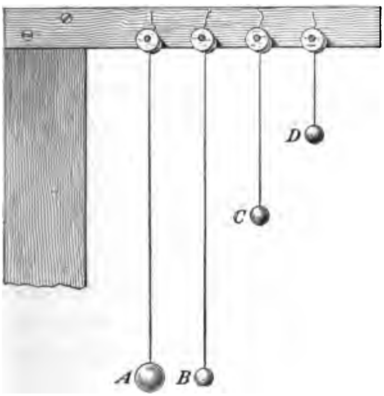


FIG. 64

From an extension of the above experiment it is found that the relation between the time of vibration, or *period*, of a pendulum and its length may be expressed by the formula

$$t = 2\pi\sqrt{\frac{l}{g}}, \tag{26}$$

in which t is the time, in seconds, of one complete vibration, and l is the length of the pendulum.[1] In a pendulum of this type the length is from the point of support to the middle of the ball.

[1] The character π (called *pi*) represents the ratio of the circumference to the diameter of a circle, or nearly 3.1416; and g represents the acceleration per second per second due to gravity.

Another pendulum of length l' will vibrate in the same place in the time $t' = 2\pi\sqrt{\frac{l'}{g}}$, and hence we get the proportion

$$t : t' = \sqrt{l} : \sqrt{l'}. \tag{27}$$

The times of vibration of two pendulums are proportional to the square roots of their respective lengths, and are independent of their weights and of their amplitudes of vibration.

91. The Seconds Pendulum. — The vibration, which has been defined as the to-*and*-fro movement of a pendulum over its path, is called a *complete vibration* in order to distinguish it from the to-*or*-fro movement, which may be called a *half vibration.* If t were taken as the time of a half vibration, the formula would become $t = \pi\sqrt{\frac{l}{g}}$. When the time of a half vibration is one second, the pendulum is called a *seconds pendulum;* and by solving the equation we find its length to be $l = \frac{g}{\pi^2}$.

The value of g at Philadelphia is 980.18 cm. Hence the length of the seconds pendulum there is

$$l = \frac{980.18}{(3.1416)^2} = 99.3 \text{ cm.}$$

92. The Compound Pendulum. — Any body suspended so as to vibrate in a vertical plane under the influence of gravity alone is a *compound pendulum.* The form generally used for practical purposes is that of a metallic bob suspended by a thin wire. The bob is made lens-shaped, or thin on the edges, to offer less resistance to the air, and is arranged so that it can be raised or lowered on the wire to regulate the length of the pendulum.

93. Length of the Compound Pendulum.— Demonstration.— From a suitable support (Fig. 65) suspend five pendulums, *A*, *B*, and *C* being of wood, and shaped as in the figure. Vibrate them in pairs. Do they vibrate in the same time? They are all of the same length as sticks; are they of the same length as pendulums? Vibrate each one with *D*, changing the length of the latter until they vibrate in the same time. Which is the shortest as a pendulum? Which is the longest? Now

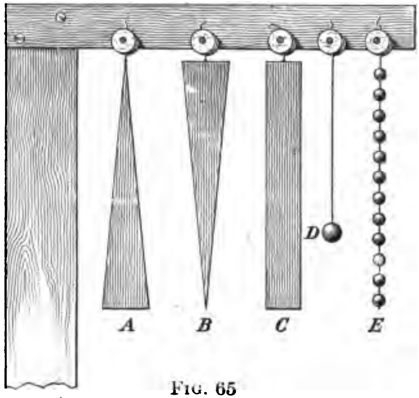


FIG. 65

take the end of the pendulum *E*, — which is made by cutting gashes in shot and pinching them upon a thread, — draw it aside and let it swing. Do the shot form a straight line or a curve? Why?

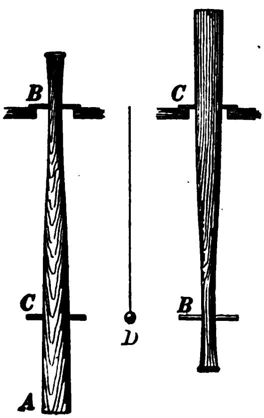


FIG. 66

94. Axis of Supension; Centers of Oscillation and Percussion. — Demonstration. — Bore a quarter-inch hole through the handle of a baseball bat near the end. Drive in a piece of dowel pin for an axis, and suspend it as in *A* (Fig. 66). Set it vibrating, and determine its length as a pendulum by comparison with the simple pendulum *D*. Mark off this length *BC* from the lower side of the pin *B*, and put a second pin through, with its upper side at *C*. Invert the bat and vibrate from *C*, and it will be found to vibrate in the same time as before.

The axis at B, in the left half of Fig. 66, is the *axis of suspension.* The point C is the *center of oscillation,* and the demonstration shows the important fact that the axis of suspension and center of oscillation are *interchangeable.*

The point C is also the center of percussion, and a ball striking the bat at this point will receive the full effect of the blow. The position of the hands in holding the bat and the swing given to it will change the position of the center of percussion slightly. If the ball is struck too far from this point, the effect will be to sting the hands.

95. The Determination of g. — By making the axes of a pendulum similar to the one described in the preceding section in the shape of knife-edges it is possible to measure the length of this form of pendulum (Kater's) very accurately. The distance between the knife-edges being the length of a simple pendulum that vibrates in the same time, it can be substituted for l in Formula 26, from which

$$g = 4\frac{\pi^2 l}{t^2}.$$

By substituting also the time t determined by experiment, the value of g is determined.

96. Uses of the Pendulum. — The most common use of the pendulum is as a timekeeper. Since the vibrations are performed in equal intervals of time (*i.e.*, are isochronous), all that is needed is to make the to-and-fro motion of the pendulum regulate the rotary motion of the hands. This is done by the use of an escapement by means of which each complete vibration lets one tooth of a cogwheel escape, so that if the wheel has 30 teeth, it will rotate once while the pendulum vibrates back and forth 30 times. This wheel is

one of a train of cogwheels that move the hands. The motion of the pendulum is kept up by a push from each cog as it escapes, and the motion of the train is kept up by the pressure of a spring or by the pull of a weight. In order that the times of vibration may be equal, the length must always be the same, and corrections must be made for the changes in length due to changes of temperature. In most pendulums this is done by moving the bob up or down by means of a nut running upon the wire support. It is done automatically in various forms of compensation pendulums. In some of these two different sets of metal rods are used so that the expansions shall oppose each other. In the mercurial pendulum (Fig. 68), glass tubes filled with mercury are used for the bob, and are so arranged that the expansions and contractions of the mercury just counteract the effect of the contraction and expansion of the suspending rod.

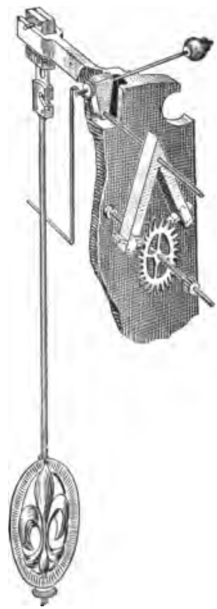


FIG. 67

FIG. 68

Questions

1. What force keeps a pendulum vibrating?
2. What force brings it to rest?
3. Does changing the weight of a pendulum bob change the time of vibration?
4. Does changing the amplitude change the time of vibration?

5. Does changing the length change the time of vibration?

6. State, in the form of a proportion, the relation between the numbers of vibrations per second and the times of vibration of two pendulums.

7. Do the same for the numbers of vibrations and the lengths.

8. A certain pendulum vibrates twice in a second. How many times per second will another pendulum vibrate in the same place if it is two and a quarter times as long?

9. A certain pendulum vibrates once in one third of a second. What must be the relative length of a pendulum to vibrate once in two thirds of a second at the same place?

10. A certain pendulum clock loses time. How can it be made to give correct time?

Problems

1. What must be the length, in centimeters, of a pendulum at New York to make a half vibration in $1\frac{1}{2}$ sec.?

2. What is the time of a half vibration of a 4-ft. pendulum at New York?

3. What is the length of a seconds pendulum at the Smithsonian Institution in Washington, D.C., 10 m. above sea level, where the value of g is 980.1?

4. On Pikes Peak, at an elevation of 4293 m., the value of g is 979.94. Find the length of a seconds pendulum there.

5. At Yakutat Bay, Alaska, at an elevation of 4 m., the length of the seconds pendulum is 99.479 cm. Find the value of g there.

6. Explain the reasons for the different values of g given in these problems.

V. MACHINES

97. **A Machine** is a mechanical device used to apply force advantageously. If a machine could be made to operate without friction, the *work* applied by it would be exactly equal to the work employed in operating it. Since it is impossible to make such a *perfect machine,* the work applied by a machine, *the output,* is always less than the work put into it, *the input.*

98. Efficiency. — The efficiency of a machine is the ratio of the work actually applied by it, to the work that would be applied if it had no friction. Various devices are adopted for increasing this efficiency by making the friction as little as possible, one of the best being ball bearings such as are used on bicycles. Efficiency is expressed as a per cent. An efficiency of 92 % means that of every 100 parts of *total work*, there are 92 parts of *useful work*, and 8 parts lost by friction. The expression for efficiency is as follows:

$$\text{Efficiency} = \frac{\text{Useful work}}{\text{Total work}} = \frac{\text{Output}}{\text{Input}},$$

or

$$E = \frac{W_u}{W_t}. \tag{28}$$

99. The General Law of Machines. — The work of a machine consists in the overcoming of some force, which we call *resistance* or *weight*, while the force applied in operating the machine is called *effort* or *power*. A law that is applicable to all machines is: *The power multiplied by the distance through which it acts is equal to the resistance multiplied by the distance through which it is moved;* or,

$$Pd = RD. \tag{29}$$

Each machine has its own law, which is generally more convenient than the above. But this law is general, and may be applied to any machine or combination of machines. It is evident that the R in Formula 29 should include the friction of the machine as well as the resistance to be overcome in useful work; but in most problems in simple machines we consider only the conditions of static equilibrium, and neglect the friction.

Rev.

100. Mechanical Advantage. — While no machine can give an increase in *work*, there can be an increase in either speed or force. The ratio of the force overcome as resistance, to the force employed as power, is called the *mechanical advantage* of the machine with respect to force, provided this ratio is greater than 1; while the ratio of the speed of the resistance, to the speed of the power, is the mechanical advantage in speed, provided this ratio is greater than 1. The mechanical advantage is usually given as it would be if the machine were operated without friction.

For instance, suppose that a machine moves a resistance of 1000 pounds of force a distance of 5 feet, and that the work needed to operate it (in addition to overcoming the friction of the machine) is a force of 100 pounds moving over a distance of 50 feet. The mechanical advantage of force would be the ratio of 1000 to 100; namely, 10. (In actual operation a force of perhaps 110 pounds instead of 100 would be required, in which case the efficiency would be $\frac{1000 \times 5}{110 \times 50}$, or nearly 91 %.)

For any increase in force through the mechanical advantage there is a corresponding decrease in speed, and for any increase in speed there is a corresponding decrease in force. This means again that there can be no gain in the work done through the use of a machine.

101. Simple Machines. — The many more or less complicated machines in common use may be reduced in principle to but six: the lever, pulley, wheel and axle, inclined plane, wedge, and screw. These are called the *mechanical powers* or *simple machines*. These six simple machines may be still further reduced to two, the lever and the inclined plane, as it can easily be shown that the pulley and the wheel and

axle are only modified levers, while the screw and the wedge are modified inclined planes.

102. The Lever is a rigid bar that is capable of movement about a fixed point called the *fulcrum*. There are three classes of levers, which are distinguished by the relative positions of the fulcrum and of the points of application of the applied force (power) and the resistance (weight).

(*a*) *Levers of the First Class.*—In a lever of the first class (*AB*, Fig. 69) the power is applied at one end and the weight at the other, with the fulcrum between them.

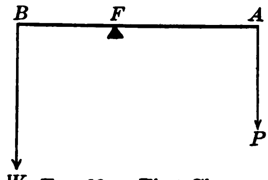


FIG. 69.—First Class

The mechanical advantage in levers of this class may be either of speed or of force. If the power arm is greater than the resistance arm, the mechanical advantage is one of force; while if the power arm is less than the resistance arm, it is one of speed.

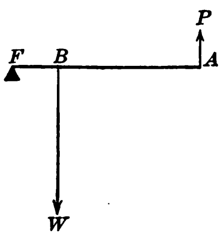


FIG. 70.—Second Class

(*b*) *Levers of the Second Class.*—In a lever of the second class (Fig. 70) the power is at one end and the fulcrum at the other, with the weight between them.

In levers of this class the mechanical advantage is always one of force. It can never be one of speed, since the resistance arm is always less than the power arm.

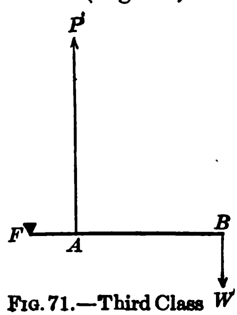


FIG. 71.—Third Class

(*c*) *Levers of the Third Class.* —The lever of the third class (Fig. 71) has

the weight at one end and the fulcrum at the other, with the power between them.

The mechanical advantage in this class of levers is always one of speed, since the resistance arm is greater than the power arm.

103. The Law of Equilibrium of the Lever. — By applying the principle of moments, we can readily find an expression for the law of the lever. As F is fixed in every case, it is the center of moments, and when the lever is in equilibrium, the moment of P equals the moment of W. Hence $P \times AF = W \times BF$. Writing this as a proportion, we have

$$P : W = BF : AF,$$

or Power : Weight = Weight arm : Power arm,

in which "arm" means the perpendicular from the fulcrum to the direction of the force. Using the more general term Resistance in place of Weight, we write the formula thus:

Power : Resistance = Resistance arm : Power arm. (30)

The mechanical advantage of any lever is the ratio of the longer arm to the shorter arm.

If additional forces are applied at different points along the lever, equilibrium will be maintained when the sum of the moments producing clockwise rotation is equal to the sum of the moments producing counterclockwise rotation. Moments producing counterclockwise rotation are sometimes called positive, and those producing clockwise rotation negative: if this is done, equilibrium will be maintained whenever the sum of all the moments is zero.

If a body is acted on by a number of forces and is in equilibrium, any point at which force is applied may be taken as the center of moments, when the sum of the clockwise

moments with reference to this point will be equal to the sum of the counterclockwise moments. This is true however great the number of forces, and whether they are parallel or not. If A in Fig. 69 is taken as the center of moments, W tends to produce a counterclockwise rotation which is counterbalanced by the pressure of the fulcrum upon the lever at F. This pressure at F is upward in direction, and is equal to $P + W$, the pressure that P and W exert upon the fulcrum.

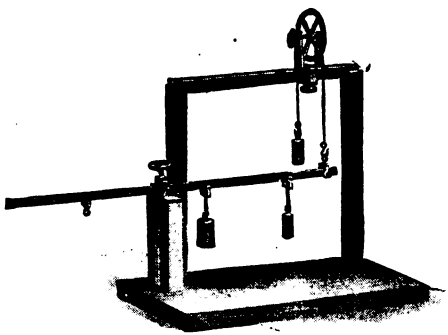


FIG. 72. — Algebraic Balance

Demonstration. — The equality of moments may be demonstrated by the use of the algebraic balance (Fig. 72).

The moments of the weights hung directly on the bar are clockwise. The moment of the weight hanging from the cord passing over the fixed pulley is counterclockwise. To produce equilibrium these must counterbalance each other. By different arrangements of the weights the three classes of levers can be illustrated.

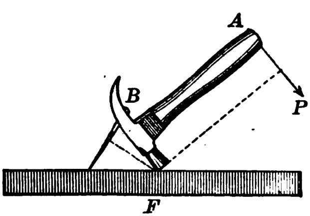


FIG. 73

104. The Bent Lever. — When a hammer is used to draw a nail, it is a lever of the first class, though the fulcrum is not in a straight line joining the points of application of the power and the resistance. This constitutes a *bent lever*. The law of moments holds for it. For Formula 30 the " arms " are the dotted lines in Fig. 73.

105. The Common Balance is a lever of the first class with equal arms, hence in this case $P = W$. In order that the balance may be accurate, the arms, or parts of the beam on each side of the fulcrum, must be of equal weights and lengths. In order that it may be sensitive, the arms must be light, the friction must be little, and the knife-edge fulcrum must be very close to a line joining the knife-edges of the scale pans, with the center of gravity of the arms just below it.

Even if a balance does not fulfill the conditions for accuracy, the true weight of a body may be found with it by the *method of substitution* as follows: First counterbalance the body exactly by putting sand or any other convenient substance in the other scale pan. Then remove the body and substitute for it known weights until they exactly counterbalance the sand. The sum of the weights required will be the weight of the body.

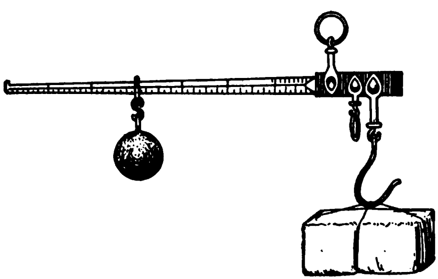


FIG. 74

106. The Steelyard (Fig. 74) is a lever of the first class with unequal arms. By having one hook to which the article to be weighed is attached, and two, by either of which the steelyard may be supported, both sides of the bar are used, one for light and the other for heavy bodies.

107. The Compound Lever. — If the short arm of one lever is made to work upon the long arm of a second, the combination is called a *compound lever*. The mechanical

advantage is the ratio of the product of the long arms to the product of the short arms. The platform scale (Fig. 75)

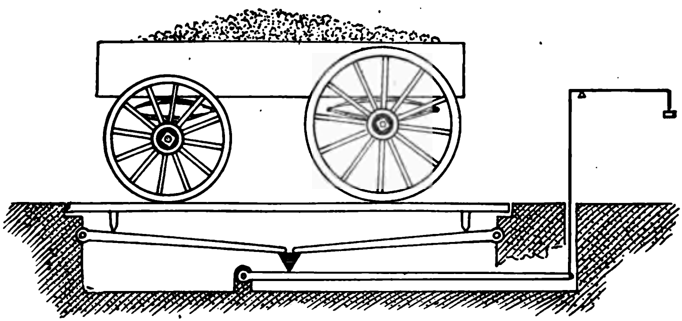


FIG. 75. — Platform Scale

used for weighing hay and coal is an example of its application.

108. The Wheel and Axle is a modified lever, the arms being the radii of the wheel and the axle. The power is usually applied at the circumference of the wheel, and the weight at the circumference of the axle. In Fig. 76 the power is applied at A, the weight at B, the fulcrum is at C (the center of both wheel and axle), and the lever arms are R and r respectively; the arrangement is a modified lever of the first class.

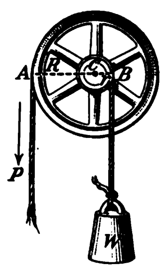


FIG. 76

109. Law of the Wheel and Axle. — Since the moment of the power must equal the moment of the weight whenever there is equilibrium, we have, from Fig. 76, $PR = Wr$; or, in the form of a proportion,

$$P : W = r : R. \tag{31}$$

This can be stated as follows: *A certain power applied to the wheel and axle can support a weight as many times greater*

than itself as the radius of the wheel is times greater than the radius of the axle. The radii in Formula 31 can be replaced by either the circumferences or the diameters if it is more convenient.

The mechanical advantage of the wheel and axle is the ratio of R to r. If the power and weight are disposed as in Fig. 76, the mechanical advantage is one of force; if the points of application of P and W are interchanged, it is one of speed.

FIG. 77.—The Capstan

The wheel and axle is used to raise water from a well, to hoist ore from a mine, as with the windlass, to move buildings, and to raise anchors, as with the capstan. In the capstan no wheel is used, but instead straight bars, called hand-spikes, are put into holes in the head of the capstan, and the power is applied to these.

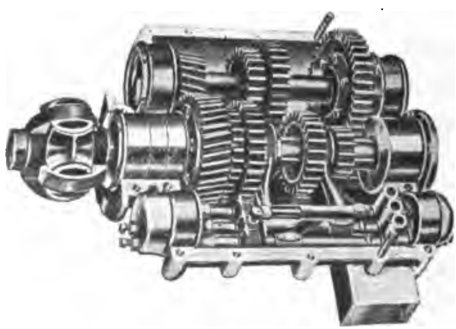


FIG. 78.—Automobile Transmission Gearing

110. Combinations of the Wheel and Axle, with the axle of one system working upon the wheel of another, are used, not only where great weights are to be lifted, but also where it is desired to make a great difference in speed between the movement of the power and of the resistance.

These results are usually secured by the use of a train of cog wheels such as is shown in Fig. 78, which represents a set of automobile transmission gearing.

111. The Pulley. — The fixed pulley, in which the axis of the pulley is held in a fixed position is a modified lever of the first class; but in this machine the power arm is always equal to the weight arm, so that there is no gain in using it, except change in direction. This may be seen readily by reference to Fig. 79. The power is applied at one end of a rope that passes around the pulley in a groove cut in its edge, and is tangent at the points A and B. Apply the law of the lever, and the proportion will stand

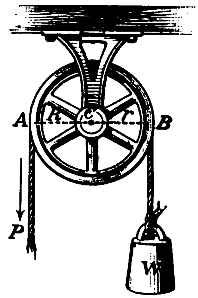


FIG. 79

$$P : W = r : R;$$

but $r = R$, $\therefore P = W$. (32)

112. The Movable Pulley, in which the axis of the pulley can move with it, is a modified lever, but it is of the second class, the fulcrum being at B (Fig. 80), the weight (including the weight of the pulley) being applied at C with a lever arm $CB = r$, and the power at A with a lever arm $AB = D$. The formula for the single movable pulley is $P : W = r : D$, and since D is the diameter and r is the radius of the pulley, this becomes

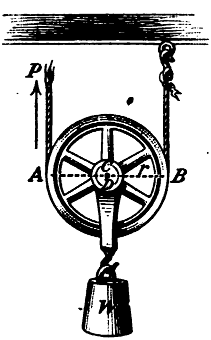


FIG. 80

$$P : W = 1 : 2,$$

or $P = \frac{1}{2} W$. (33)

113. Combinations of Fixed Pulleys. — Figure 81 shows how, by a combination of fixed pulleys, the horizontal pull of a horse can be used to raise a heavy weight. The mechanical advantage secured by the movable pulley would frequently be useless if it were not for combining with it one or more fixed pulleys by which the direction of the pull can be changed.

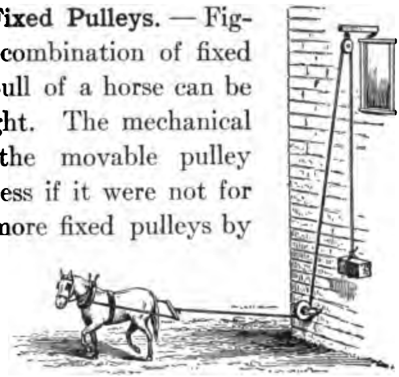


FIG. 81

114. Systems of Fixed and Movable Pulleys. — Where great weights are to be raised, systems of pulleys are used. Usually a number of "sheaves" or pulleys are arranged side by side in the same block, and a single rope is passed alternately around the sheaves in two of these blocks, called the "block and tackle" (Fig. 82). Another arrangement is shown in Fig. 83. The weight is attached to the movable block A (Figs. 82 and 83), and since the rope is continuous there must be the same pull on each branch between the blocks. If we let n represent the number of branches extending to the movable block ($n = 6$ in Figs. 82 and 83), then by § 62 each branch must support $\frac{1}{n}$ of the weight;

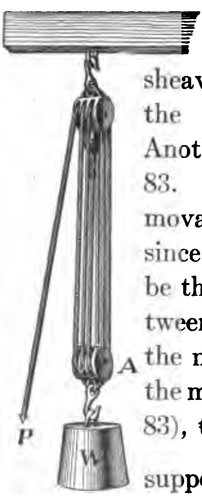


FIG. 82

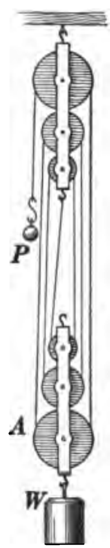


FIG. 83

and
$$P = \frac{W}{n}. \qquad (34)$$

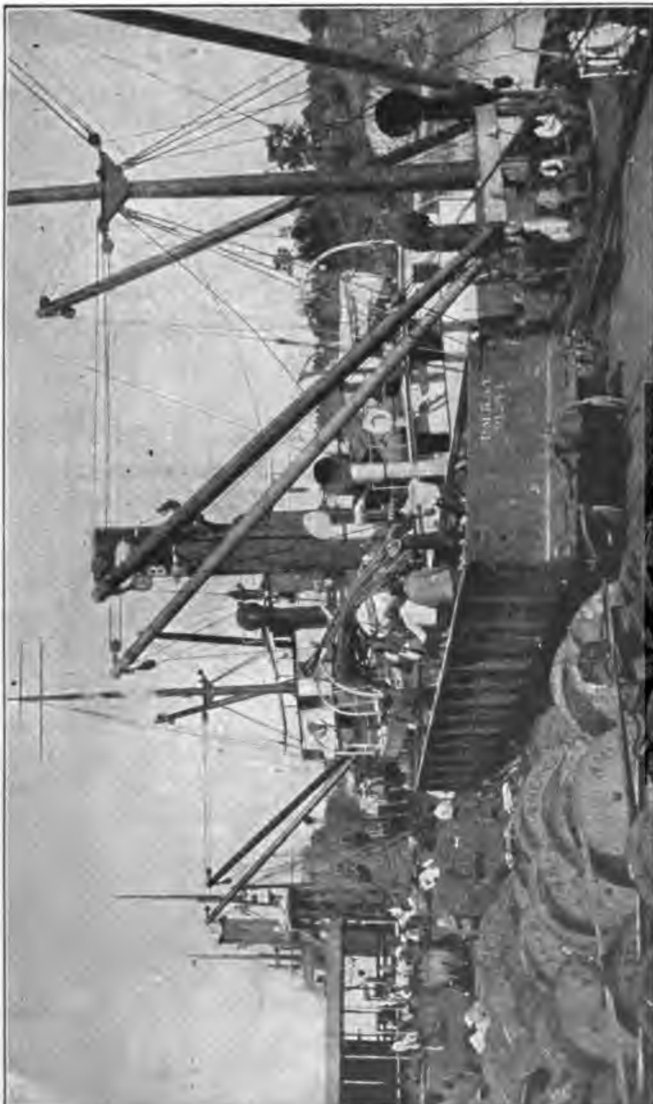


FIG. 84. — Fixed and Movable Pulleys in Use

115. The Inclined Plane. — Any plane surface that makes an angle with a horizontal surface forms an *inclined plane.* A ball placed upon a horizontal plane will retain its position and will press upon the plane with its entire weight. As soon, however, as one end of the plane is raised, the entire weight of the ball will not rest upon the plane, and it will begin to roll toward the lower end. The only way in which an inclined plane can be used efficiently is to have the moving

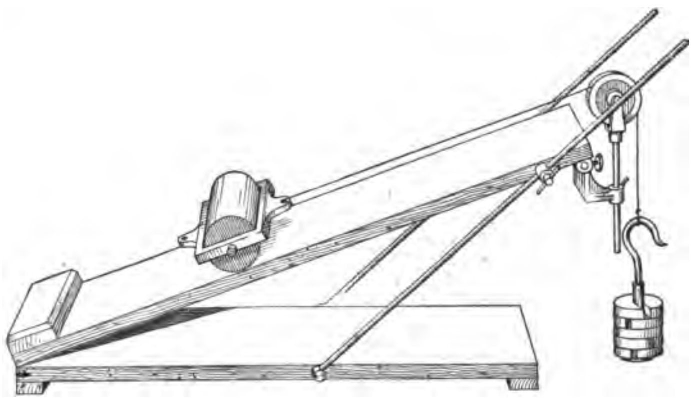


FIG. 85

force act in a direction that is parallel to the inclined surface of the plane. Inclined planes are used for the purpose of lifting a weight to a certain height by the use of a small power. The power which moves a body from the bottom of the plane to the top lifts it through the height of the plane against gravity and hence the general law of machines will apply. This may be modified to read

$$PL = WH, \text{ whence } P : W = H : L, \qquad (35)$$

in which H is the vertical height of the plane and L is the length along the slope.

A demonstration of the law of the inclined plane can be made with an apparatus like that shown in Fig. 85. The cylinder is the weight and the pull of the power is made parallel to the plane by means of the cord running over the fixed pulley at the top.

116. The Wedge is nothing more than a modified inclined plane. It is generally made with its base (which corresponds to the *height* of an inclined plane) perpendicular to a line drawn from the edge to the middle of the base. This means that it is made of two inclined planes placed base to base. The power is usually applied by the blow of a heavy body. Wedges are used in splitting logs and stone, raising heavy weights a short distance, launching ships, and similar operations.

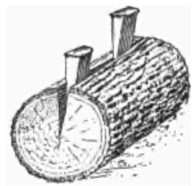
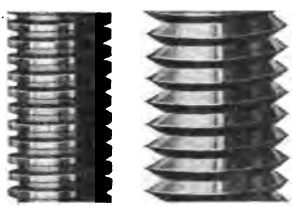


FIG. 86

117. The Screw consists of a cylinder of wood or metal about which is a thread. If the cross section of this thread is square, the thread is called a square thread; if triangular, it is called a V-thread. A good model of a square-thread screw can be made by winding a long strip of leather in a spiral around a wooden cylinder, and tacking it fast.



Square Thread V-thread

FIG. 87.—Screws

That the screw is a modified inclined plane may be seen by cutting a right-angled triangle out of paper and winding it about a pencil as in Fig. 88. It will be seen that the hypotenuse, which represents the length of an inclined plane, forms the spiral thread of the screw. If

CB is taken equal to the circumference of the pencil, then *AB* will be equal to the distance between the threads *DE*. This distance is called the *pitch,* and determines how far the screw (or the resistance) moves at each revolution. The power is generally applied to a screw at the end of a lever, as the handle of a wrench. It is applied either to the screw or to the nut, as in bolting two pieces of wood together.

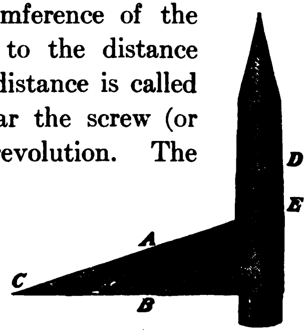


FIG. 88

118. The Law of the Screw. — The mechanical advantage of a screw cannot be determined unless we know at what point the power is applied. From the general law of machines, the formula can be written $P \times 2\,\pi R = Wp$, or

$$P : W = p : 2\,\pi R, \tag{36}$$

in which p is the pitch of the screw, and R is the radius of the circle through which the power moves.


FIG. 89. — Lifting Jack

119. Application of the Screw. — Lifting jacks, cotton and hay presses, the screw propeller of ships, and air fans are familiar examples of the practical uses to which the screw is put, besides the constant use that is made of it in machinery and woodworking. The spherometer and mi-

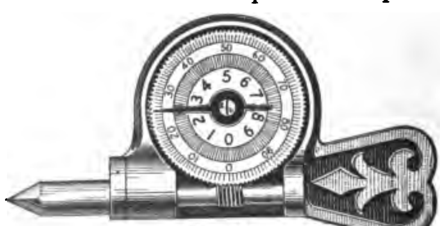


FIG. 90

crometer screw are examples of its use in scientific work. The speed counter shown in Fig. 90 shows how an endless screw, meshing into teeth on the circumference of a wheel, can be used to determine the rotation of an axle, the pointed end of the screw being thrust into a hole in the end of the axle and rotating with it.

120. Friction. — Whenever any body is put in motion by sliding or rolling it over another, and the body is then left to itself, its velocity will gradually diminish, and it will come to rest. This is due to *friction,* which is *the resistance that is encountered in moving (or trying to move) one body over another under pressure.* Friction arises from inequalities in the surfaces in contact. If any means is taken to reduce these inequalities, either by making the surfaces smoother, or by filling up the depressions with some form of lubricating material, the friction is diminished.

121. Laws of Sliding Friction. — Experiment has established the following law for sliding friction — both for *friction of motion* and for *friction of rest:*

Sliding friction is proportional to the pressure, and independent of the extent of the surfaces in contact. It varies with the character of the surfaces.

Within certain limits friction of motion is also independent of the velocity of the motion.

122. Coefficient of Friction. — The coefficient, or measure, of sliding friction — either of rest or of motion — is expressed by the equation

$$f = \frac{P}{W}, \qquad (37)$$

in which P is the force necessary to overcome the friction, and W is the pressure normal (perpendicular) to the surfaces in contact. A simple method of determining this, for friction of rest, is to place a block of known weight, W, upon a level board, and set it in motion by putting weights in a scale pan suspended as in Fig. 91. In measuring friction of motion care must be taken that the speed is uniform.

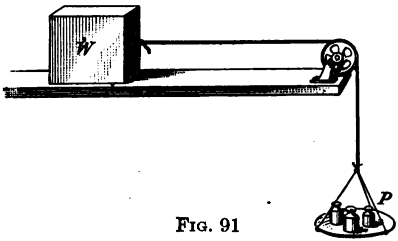


FIG. 91

123. Rolling Friction. — If two equal masses of iron are drawn over a smooth iron surface, one being in the form of a block with a flat base and the other in the form of a cylinder so arranged as to roll, it will be found that the cylinder offers much less resistance to the motion than the block does. *Rolling friction* depends upon the hardness and smoothness of the surfaces in contact. When these are very hard and smooth, rolling friction is much less in amount than sliding friction — as in the case of a car wheel running on a steel track. If, however, the surface over which a wheel rolls is soft and yielding, as in the case of a wagon in deep sand, rolling friction may be even greater than sliding friction. In such a case the wheel has to be constantly climbing the hill caused by the sinking of the wheel in the sand. If the wheel is yielding,


FIG. 92. — Ball Bearings

as in the case of an automobile tire that is not well filled with air, the wheel is flattened at the point of contact, thus increasing the rolling friction.

The efficiency of machines is increased by changing sliding friction to rolling friction, by the use of hardened steel cylinders or balls placed between the axle and the bearing. In roller bearings, the contacts are line contacts, while in ball bearings, they are point contacts.

124. Advantages of Friction. — While all possible means are taken to reduce the friction between the parts of a machine that move over each other, friction has many advantages. The difficulty of walking on an icy pavement illustrates the decrease of stability that comes with a decrease of friction. The stability of the ceiling of a room is dependent upon the friction between the lath nails and the joists. Horses that easily draw a heavy load over a dry pavement will fall when the pavement is wet. The ability of a locomotive engine to haul its train is due to the friction between the driving wheels and the rails. If the rails are wet, the wheels slip until sand is sifted over the rails.

Questions

1. Is a perpetual motion machine possible? Why?
2. What effect upon the efficiency of a machine does it have to reduce its friction?
3. State the general law of machines.
4. Name three machines in which the mechanical advantage is one of speed. Which is greater in each case, the power used or the resistance overcome?
5. What point is the center of moments in a lever?
6. Draw a figure of a lever of the first class, in which the moment of the power and the moment of the weight shall each be 80.

Rev.

7. With which class of lever will a force of 100 lb. raise the greatest weight, the lever being 12 ft. long and the weight arm 2 ft. long? Prove your answer by a figure.

8. Which class of lever is represented by a pair of shears? Sugar tongs? A wheelbarrow? An oar in rowing a boat?

9. A ladder lies upon the ground with its foot against a house. Show by a figure how it changes from one class of lever to another when a man takes it by the top and raises it slowly to a vertical position by lifting successively on rungs nearer and nearer the foot.

10. Locate the positions of the power, fulcrum, and resistance in a pair of sugar tongs, a pair of blacksmith's tongs, a loaded pitchfork.

11. Why does moving the fulcrum nearer a stone to be raised make it easier to raise the stone with a crowbar?

12. In what class of lever is the weight a help? In what class a hindrance?

13. With a given length of handspike would you choose a capstan with a large or small barrel for raising a heavy anchor?

14. Which would you choose if you wanted to raise it quickly?

15. How much can a man raise with a single fixed pulley?

16. Would you prefer to roll a barrel of flour into a wagon up a plank used as an inclined plane or to push a box of equal weight up the plank? Why?

17. In what way is friction between the tires of an automobile and the road helpful? In what way is it harmful?

Problems

1. What is the efficiency of a machine in which 10% of the power is lost in overcoming the friction?

2. What is the efficiency of a machine with which a power of 25 lb. moving 30 ft. can move a resistance of 130 lb. of force through a distance of 5 ft.?

3. In a lever of the first class a force of 25 lb. balances a load of 275 lb. The force arm is 2.2 ft. Find the load arm. What is the mechanical advantage?

4. Make a drawing of a lever of the second class in which a force of 25 lb. supports a load of 275 lb.

5. In Fig. 93 the numbers on the lever represent distances from the fulcrum in feet, and the numbers at the arrow points represent pounds of force. Where must a force of 36 lb. be applied to put the system shown in equilibrium, if we assume that the lever by itself will balance on *F*? What will be the amount and directions of the pressures at *F*?

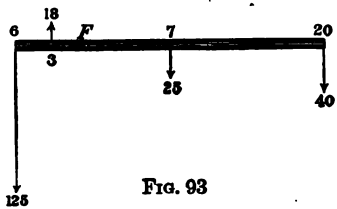


FIG. 93

6. What will be the answers in problem 5 if the lever weighs 2 lb. per running foot so that it will not by itself balance on *F*?

7. A filbert is placed three quarters of an inch from the hinge of a nutcracker while the hand is 5 in. from the hinge. What pressure acts upon the filbert when the hand presses 2 lb.?

8. A man lifts 25 lb. of hay with a pitchfork 5 ft. long, by placing his right hand at the end of the handle and his left hand 3 ft. from the end. How much must he lift with his left hand?

9. A boy who can lift 100 lb. tries to raise the end of a 250-lb. iron bar lying on the ground. How much must a second boy lift so that together they can raise the end from the ground?

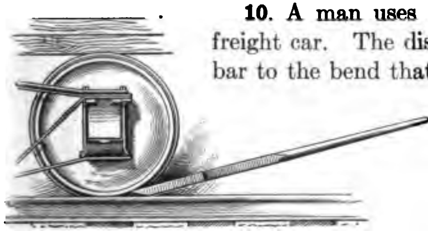


FIG. 94.—Pinch Bar

10. A man uses a pinch bar for starting a freight car. The distance from the end of the bar to the bend that rests on the rail is 4 ft. and 9 in. The distance from the bend to the point that touches the wheel is 3 in. What is the mechanical advantage of the bar, and how great a force does the man exert upon the wheel when he pushes with a force of 75 lb. at the end of the bar?

11. A wooden beam weighing 55 lb. per cubic foot is used to pry up a block of stone. How much does it help to lift the stone if it is 12 ft. long, 8 in. square, and the fulcrum is 1 ft. 6 in. from the end under the stone?

12. The crank of a grindstone is 9.5 in. long and the diameter of the stone is 22.5 in. What resistance at the rim of the stone will be balanced by a force of 12.5 lb. at the crank handle?

13. A wheel of a wheel and axle is 25 in. in circumference. What must be the circumference of the axle if a pull of 8 lb. on the wheel is to balance the pull of a 36 lb. pail suspended from the axle?

14. The drum of a winch is 2½ ft. in diameter, and the shaft 1 ft. in diameter. What must be the pull on a rope wound around the drum to balance the pull of a 2000-lb. rock being lifted by the rope wound around the shaft?

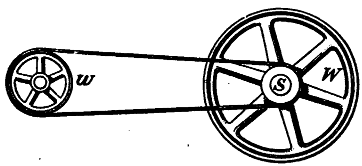


Fig. 95

15. A wheel w turns 10 times per second and is 10 in. in diameter. This is belted to a shaft S, 6 in. in diameter, upon which there is fixed a wheel W, 24 in. in diameter. What is the speed of a point on the circumference of W?

16. The wheel of a wheel and axle is 3 ft. and the axle 6 in. in diameter. How many times must the wheel turn per minute to raise a weight suspended from the axle at the rate of 100 ft. per minute?

17. Two cogwheels that mesh into each other have 8 and 44 teeth respectively. What is the relative rate of rotation of the wheels?

18. In the steelyard shown in Fig. 96, the distance from the fulcrum to the parcel hook is $2\frac{1}{2}$ in. How far must the weight w be from the fulcrum if it weighs 6 oz. and the parcel weighs 3 lb.?

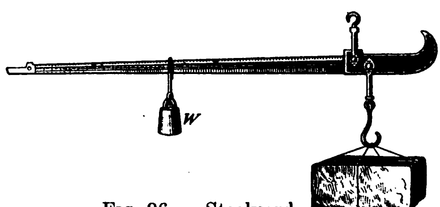


Fig. 96. — Steelyard

19. A capstan (Fig. 77) with a barrel 10 in. in diameter is used to raise a 500-lb. anchor from a depth of 100 ft. The handspikes are 3 ft. long, measured from the middle of the barrel, and each man pushes at a point 4 in. from the end. How much must each of two men push to raise the anchor, if the friction increases the load 25%, and how far will each one walk?

20. A horse pulling on the rope of Fig. 81 raises a weight of 500 lb. to a height of 12 ft. The friction increases the load 10%. How much must the horse pull and how far must he walk?

21. What is the pull supported by the rope of a block and tackle of three pulleys in the movable block and three pulleys in the fixed block, when the weight supported is 624 kg.? How far must the power move to raise the weight 3 m.?

22. Suppose the rope to be fastened to the movable block mentioned in problem 21 and one more pulley to be added to the fixed block. How many branches of rope will extend to the movable block? Make a drawing to show the arrangement, and compute the pull on each rope.

23. An inclined plane is 13 ft. long and 3 ft. high. What is the mechanical advantage of the plane? What force acting parallel to its length would be required to pull a car weighing 156 lb. up the incline if there were no friction?

24. The length of an inclined plane is 300 ft. and its height 25 ft. What force parallel to the length of the plane is required to draw a loaded truck weighing 5 short tons up the plane if the friction increases the load 10%?

25. A wagon weighing 750 lb. is loaded with 1 ton (2240 lb.) of coal. Besides overcoming friction, how much must a horse pull to draw the wagon and coal up a hill 200 ft. long and 40 ft. high? What horse power is developed by the horse if the work is done in 2 min.?

26. Neglecting friction, what horse power is developed by a 3000-lb. automobile going up a 10% grade at 30 mi. per hr.?

27. How much pressure, neglecting friction, is brought to bear upon a book in a letter press, if the threads are $\frac{1}{4}$ in. apart and the diameter of the hand wheel is 14 in., when the pull on the rim is 10 lb.?

FIG. 97. — Letter Press

28. A screw having 40 threads to the inch has a head 2 in. in diameter. At what speed is the screw moved when it is turned around once in three seconds? What is the speed of a point on the circumference of the head?

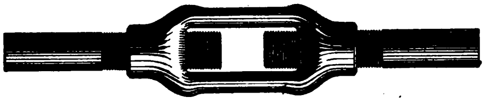


FIG. 98. — Turnbuckle

29. This turnbuckle has 16 threads to the inch. The ends of the rods to which it is threaded are 1 in. apart. How far apart are they after 6 complete turns?

30. A jackscrew with a pitch of one half inch has a handle 2 ft. long. Neglecting friction, how much pressure will a pull of 75 lb. at the end of the handle produce at the end of the screw? How far will the end of the screw move when the end of the handle passes over a distance of 10 ft.?

31. What is the coefficient of friction if a force of 7 lb. is required to draw a sled weighing 150 lb. at a uniform speed?

32. A piece of cast iron weighing 125 lb. was pulled across a concrete floor at a uniform speed by a pull of 45 lb. What was the coefficient of friction?

33. A cake of ice weighing 192 lb. was pulled across the ice on a lake by a pull of 24 lb. What was the coefficient of friction?

CHAPTER IV

LIQUIDS

I. MOLECULAR FORCES IN LIQUIDS

125. Cohesion, *in liquids, is the mutual molecular attraction of the particles of a liquid for one another.* Since water is the most common liquid, the demonstrations that follow will be made with water unless there is a special reason for using some other liquid.

If a glass rod is dipped in water and then removed, a drop will form on the end of the rod and will grow larger and larger as the water runs down the side until the weight of the drop becomes great enough to break it away from the rod, when, as it falls, it takes the form of a sphere. In this experiment cohesion does two things: it keeps the water from falling as soon as it runs down the side of the rod; and it gives the drop the form of a sphere.

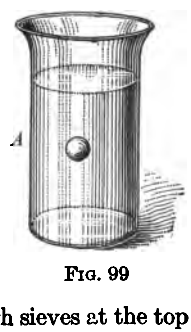


FIG. 99

The spherical form of liquids can be studied by making a mixture of alcohol and water, using such proportions that the mixture will have the same density as olive oil. Introduce a small quantity of the oil below the surface of the mixture, by the use of a glass tube, and the oil will assume the globular form, as in Fig. 99.

Shot are formed by pouring molten lead through sieves at the top of a high tower; the lead is thus separated into small masses, each of which assumes the form of a sphere.

Demonstration. — Cover a smooth board with lycopodium powder or powdered lampblack. Drop a small quantity of water

upon it from a height of 2 or 3 ft., and the water will scatter and take the form of spheres.

NOTE. — Lycopodium powder — which is made up of the spores from certain plants — can be obtained from any drug store. A few cents' worth will be found very useful for many experiments.

126. Surface Phenomena. — **Demonstrations.** — Make one end of a small brass wire very sharp, and bend it into the form of a hook. Put the hook into a glass of clean water so that the point shall be below the surface. Bring the point of the hook up to the surface, and observe that the point, before breaking through the surface, lifts it as if it were a thin flexible blanket stretched over the water. Observe that the reflection seen from the surface of the water is distorted at the point where the hook lifts the surface.

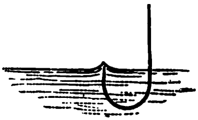


FIG. 100

Bend a wire into the shape shown at A (Fig. 101). Place a sewing needle in the hook and lay it carefully upon the surface of clean water, and the needle will float in a little depression upon the surface, as shown in the lower part of the figure. If the needle is placed below the surface, it will sink at once.

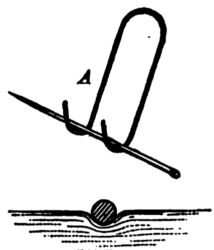


FIG. 101

NOTE. — In all experiments on liquid surfaces great care must be taken to keep the water, and everything that comes in contact with it, clean. The touch of a greasy finger is enough to change the surface tension of the water.

Certain insects make use of the above phenomena and are able to run over the surface of water, their feet resting in depressions in its surface just as the needle does.

127. Surface Tension. — Let us study the attractions acting upon a molecule at different distances from the surface, as shown in Fig. 102. At A the molecule is attracted

equally in all directions by the molecules that are within the distance of molecular attraction (cohesion); hence it can move readily in any direction. At *B*, very near the surface, the horizontal attractions are equal in all directions, but the inward (downward) attraction is greater than the outward (upward). At the surface the molecule *C* has no outward attraction, and hence it is held in place by the inward force.

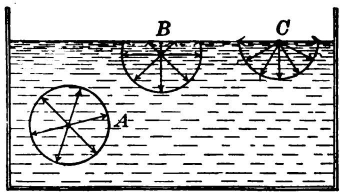


FIG. 102

As this is true of every molecule on the surface, the result is a tension upon the surface layer much greater than upon any other layer. The inward attraction tends to pull each molecule in from the surface layer, but if a molecule were drawn into the interior of the liquid, it would displace some other molecule and force it to the surface against a similar attraction; so there is no change unless the shape of the liquid body can be changed so as to decrease the area of the surface. The surface tension causes a tendency of the surface to contract to the smallest area possible. This is the reason why liquids take the spherical form (§ 125); *a sphere has a smaller surface than any other form of solid of the same volume.*

Surface tension varies with the liquid and with the temperature of the liquid. The surface tension of pure water, which is very great, compared with that of most other liquids, is illustrated by the following:

Demonstrations. — Pour some hot water into a shallow dish, like a soup plate. Cover the surface with pepper. Hold a small piece of butter in the surface of the water at the middle, and observe how the pepper goes away from the melting butter to the sides of the plate.

Spread a thin layer of clean water upon a clean glass plate, and then let a drop of alcohol fall upon the middle of it. The water will at once retreat, leaving a space around the drop of alcohol. Why?

Viscous liquids are stronger than water though their surface tension is less, and for this reason oil is sometimes thrown upon the water around a ship during a storm. The effect of this is to smooth out the surface as though a strong elastic blanket were stretched over the water; and the waves are then kept from breaking over.

A drop of kerosene placed upon water has less surface tension than the water and hence is pulled out by the tension of the water into a thin circular film.

128. Films. — If we make the thickness of the liquid mass very little, and give to it two free surfaces, surface tension may be studied to better advantage.

Demonstrations. — Make a strong solution of soap by dissolving castile soap in water until a large bubble can be blown. Bend a piece of iron wire so as to form an open frame with a handle, and from one side of the frame hang a loop *L* made of one strand of a silk thread. Dip this frame in the soap solution, and the loop will hang as at *A* in Fig. 103. Remove the film within the loop by touching it with the point of a piece of blotting paper, and the loop will at once spring out into the form of a circle, as at *B*. Why?

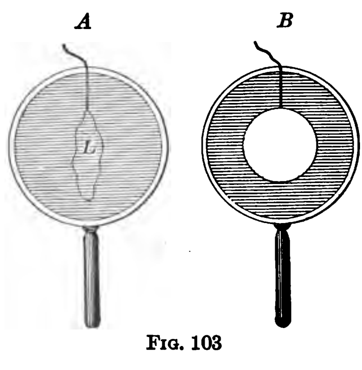


Fig. 103

Using a clay pipe or a glass tube, blow a small-sized bubble. Remove the tube from the mouth, and hold the end of it toward the

flame of a lighted candle. The pressure exerted by the surface tension of both sides of the film will force out a current of air strong enough to blow the flame to one side. What change takes place in the size of the bubble?

129. Adhesion between Liquids and Solids. — Let us consider what may happen when a solid is brought into contact with a liquid. If a lump of sugar is dipped into water, the adhesion between the two is greater than the cohesion of the sugar, and the sugar is *dissolved.* If a clean glass rod is dipped into pure water, the adhesion is greater than the cohesion of the water, and the rod will be found *wet* when it is removed. If the glass rod is dipped into mercury, the adhesion is less than the cohesion, and none of the mercury will cling to the rod.

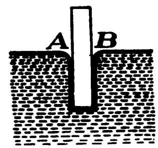


Fig. 104

When the glass rod is dipped into mercury, the surface of the liquid is not broken, but extends down beside and below the rod. The surface tension, tending to decrease the area of this surface, rounds off the corners at A and B, Fig. 104, convex upward. When the rod is dipped into water (Fig. 105), the adhesion causes the water next the glass to rise above the general level, so that the surface would be as at A if it were not for the surface tension; but the surface tension decreases the area of the surface by rounding off the corners as at B, concave upward.

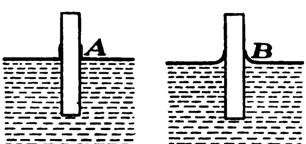


Fig. 105

If two plates of glass are thrust into water with their faces parallel to each other, the liquid will rise between them, the height being greater, the nearer the plates are to each other. If the plates are held tightly together at one edge and slightly

separated at the other, as in Fig. 106, this varying height will be shown in the form of a curve, highest at the angle, and lowest at the outside edge. This can be seen better if the water is slightly colored.

Fig. 106

Demonstrations. — Pour some clean water into a beaker, and thrust one end of a piece of clean glass tubing below the surface of the water. The water will rise on the inside of the tube to a considerable height above the water in the beaker. On removing the tube *it will be found to be wet.* Repeat the experiment with a tube of half the diameter, and the water will rise twice as high.

Pour clean mercury into a dish, and repeat the experiment,

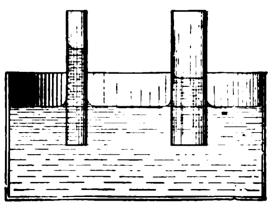


Fig. 107

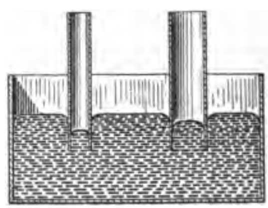


Fig. 108

using clean glass tubes of the same sizes as before. Observe that the surface of the mercury is convex and that it is depressed in the tubes. Notice also that *the glass tubes are not wet by the mercury.*

130. Capillary Tubes. — The tubes used in the preceding demonstrations — if very small — have received the name of *capillary tubes*, from the Latin word *capillus*, which means "hair." The attraction which causes liquids to go

up into minute openings is sometimes called *capillary attraction.* It is really only adhesion and surface tension. The water rises a little at the sides of a glass tube, and surface tension first makes the surface concave upward, and then tends to decrease the area of the surface by flattening the curvature. This draws the water level up higher inside the tube, and the process continues until the adhesion and surface tension are counterbalanced by the weight of the column of water above the general level.

Experiment has established the following laws:

I. *When a liquid wets the surface of a tube placed in it, the surface of the liquid will be concave, and the liquid will rise in the tube. When the liquid does not wet the tube, the surface of the liquid will be convex, and the liquid will be depressed in the tube.*

II. *The elevation or the depression varies inversely as the diameter of the tube.*

III. *The elevation or the depression decreases as the temperature rises.*

Demonstrations. — Draw from a piece of soft glass tubing a fine capillary tube. Break out a piece about a foot long, having a uniform diameter, and put one end in water. Moisten the inside of the tube by drawing it full of water and blowing it out again. Hold the tube vertically and measure the height of the water in it. Draw the tube gently from the water and notice whether there is any change in the length of the water column. Break the tube and, taking a piece an inch shorter than the length of the measured water column, put it in water as before. Does the water come out at the upper end of the tube? Explain.

131. Absorption. — Whenever a liquid is brought in contact with a porous solid, and wets it, the liquid immediately begins to pass into the pores of the solid; this process is called

absorption. Blotting paper absorbs ink, and a lamp wick, oil. When once absorbed, the liquids cannot be entirely removed by pressure. A sponge can never be pressed dry, but becomes dry only when evaporation takes place. It is evident that absorption is a capillary phenomenon and that every pore in a porous substance acts as a capillary tube.

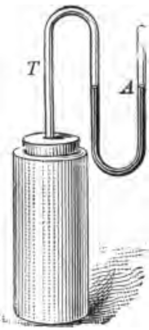


FIG. 109

Demonstration. — Procure a small porous cup such as is used for a battery cell, and fit in the open end a rubber stopper with one hole. In the stopper fit one end of a glass tube *T*, bent as in Fig. 109. Pour mercury into the end of this tube and let it come to rest at *A*. The heights in the two branches can be made the same by letting a little air out of the cup. Lower the cup into a beaker of water and observe the change in the level at *A*. Explain this action. Measure this pressure by putting a scale back of the tube at *A*.

132. Diffusion of Liquids. — **Demonstration.** — Fill a small jar three fourths full of water colored with blue litmus, and pour a small quantity of sulphuric acid carefully into the bottom of the jar through a thistle tube. The litmus will be colored red wherever the acid comes in contact with it. If now the jar is kept in a quiet place, the acid will pass through the litmus solution, and after a time the entire contents of the jar will be red. The rate at which the mixing takes place can be determined by fastening a meter stick to the jar in a vertical position and taking readings of the top of the red liquid at uniform intervals. It is interesting to observe that the plane which separates the two liquids is always exactly horizontal.

FIG. 110

This gradual molecular mixing of two liquids in contact with each other, which takes place even against the force

of gravity, is called *diffusion.* Any liquids capable of mixing will diffuse, though at different rates.

Diffusion is a proof of molecular movements in liquids. It is the vibration of the molecules of sulphuric acid that forces them upward through the water, which is lighter than the acid. If the temperature is raised, the vibration is increased, and diffusion takes place more rapidly.

133. Osmose; Osmotic Pressure. — When two liquids are separated by a porous membrane, each may pass through the membrane into the other with more or less freedom. This process is called *osmose.*

FIG. 111

Demonstration. — Tie a piece of parchment paper over the end of a thistle tube and fill the tube part way up the stem with a strong solution of copper sulphate. Thrust it into a beaker containing water, and fix it in such a position that the liquids stand at the same height, both inside and outside the tube. Set the beaker aside for some time. It will soon be seen that the height of the liquid within the tube is increasing, and if the experiment is carried on for some time, the water in the beaker outside the tube will become colored with the copper sulphate solution. This indicates that molecules have passed through the parchment in both directions, but more rapidly from the pure water than from the solution.

If in the preceding demonstration the upper end of the thistle tube is closed, there will be produced an *osmotic pressure* on the inside of the tube. This occurs because water molecules pass through the membrane more readily

than do copper sulphate molecules. Since copper sulphate molecules occupy part of the space inside, more water molecules, which are in a state of constant vibration, strike the membrane from the outside than from the inside, and for this reason more of them pass into the tube than out of it.

High osmotic pressures have been produced by the use of a semipermeable membrane made by depositing a thin surface of copper ferrocyanide within the walls of a porous cup. The simplest method of doing this is to place the cup in a solution of copper sulphate and then fill it with a solution of potassium ferrocyanide. The two substances enter the cup from opposite sides and on coming in contact form a semipermeable membrane. This acts as a molecule sieve, allowing the water molecules to pass, but not those of a solution. In one experiment of this kind a solution of sugar was used, and a pressure of 31 atmospheres (about 465 lb. per square inch) was obtained in one hour and forty-five minutes. Before another reading could be taken, the pressure became so great as to shatter the apparatus.

Questions

1. Why is a small drop of mercury, lying on a table, so nearly spherical, while a larger drop is much flattened?

2. If two straws are placed on the surface of water a half inch apart and then a drop of alcohol is placed on the surface between them, they will immediately separate. Why?

3. Suppose a silk thread to be tied loosely to two sides of the frame in Fig. 103 and the film broken on one side of the thread. What form will the thread take?

4. Why are pictures better in detail when printed on paper with a hard, smooth surface?

5. Why is it so hard to remove the stain of a drop of kerosene from marble?

6. Give examples of useful capillary action.

7. Will water rise or fall on the inside of an oiled glass tube?

8. One of the best ways to make a glass tube closed at one end is to break the tube square off at the proper length, then hold that end

in the Bunsen flame so that it will be uniformly heated. It will then soften, the opening will slowly become smaller, and finally it will make a smooth, spherical end. Why?

9. A thin plate of glass, a lantern slide plate for example, will float when tossed on the surface of water. Why?

10. A piece of cloth, the corner of which dips in a dish of water, will become thoroughly wet in a short time. Explain.

11. Water will not run out of the upper end of a capillary tube, the lower end of which dips below the surface, but sap runs from the end of a maple branch that has been cut off. Explain.

12. Could a lump of sugar be used to take up a blot of ink?

13. A glass rod is sometimes placed against the edge of a cup in pouring a liquid into another vessel. Explain its action.

14. What effect does keeping the surface of soil well cultivated have upon the evaporation of water from the surface?

Problems

1. Water rises 25 mm. in a tube of a certain diameter. What must be the diameter of a second tube in which it will rise 50 mm.?

2. If a liquid will rise 27 cm. in a tube .12 mm. in diameter, what must be the diameter of the tube for it to rise 81 cm.?

3. How high must a stone column be in order to make the pressure at the base equal to that produced by the osmotic pressure of a sugar solution, *i.e.*, 465 lb. per square inch, if the stone weighs 160 lb. per cubic foot?

II. THE MECHANICS OF LIQUIDS

134. Transmission of Pressure by Liquids. — Whenever pressure is brought to bear upon a solid, the molecules, being unable to move freely over one another, will transmit the pressure, undiminished, in one direction only. In the case of liquids, however, the free movement of the molecules over one another secures the transmission of pressure, without change, in all directions.

Demonstration. — To a thin glass bottle fit a straight cork, of such a size as to go into the neck snugly. Fill the bottle with water. Insert the cork and bring pressure to bear upon it by a lever, as in Fig. 112. The shattering of the bottle shows that the pressure was transmitted in all directions.

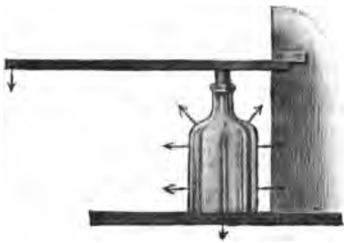


FIG. 112

The action of the molecules of a liquid in transmitting pressure may be illustrated by filling a bottle with peas and pressing upon the top layers. Since each pea does not lie directly upon another, but in a depression left between those in the next lower layer, a vertical force acting upon any pea will be resolved into other forces in the direction of the points of contact between it and the peas which it touches.

135. Pascal's Law. — Since liquids are perfectly elastic (*i.e.*, have no elastic limit) under compression, and since their molecules move freely over one another, pressure brought to bear upon any part of a liquid is readily carried to any other part. After a study of the phenomena, Pascal, a French scientist, stated this law:

Pressure exerted upon any part of an inclosed liquid is transmitted undiminished in all directions. This pressure acts with equal force upon all equal surfaces, and at right angles to them.

136. The Hydraulic Press. — An important application of the principle stated in Pascal's Law is made in the hydrostatic or hydraulic press. Figure 113 shows a simple form in section. Two pistons or plungers A and B pass through

water-tight collars into cylinders *C* and *D*. The piston *A* is moved by the lever *F* by applying the power at *P*. The body *K* to be compressed is placed between the platform *G* and a stationary framework *H* above it. The action is as follows: Both cylinders and the connecting tube *E* being full of water, the piston *A* is forced down, the pressure on the water *C* closing the valve *d*, and forcing the valve *v* open. The water displaced by *A* is forced through *E*, and passes into *D*, where it pushes *B* up, and compresses *K*. When the piston *A* is raised, the back pressure of *B* upon the water closes *v*; *d* opens, and water from some source of supply passes through it, keeping *C* full. The next stroke simply repeats the action. By Pascal's Law, if base of cylinder *B* is 20 times as large as base of cylinder *A*, the pressure on it will be 20 times as great. This may be stated as follows: The pressure applied by the small piston : The pressure delivered to the large piston = The area of the small piston : The area of the large piston,

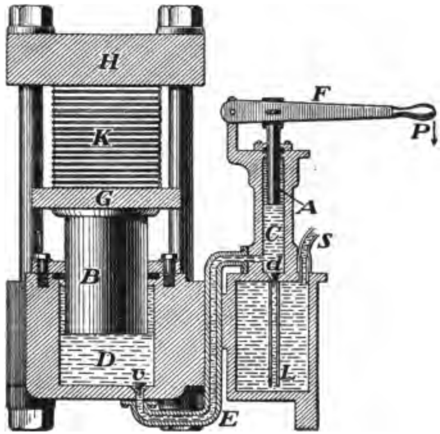


FIG. 113.—Hydraulic press

$$P : W = a : A = d^2 : D^2,$$

d and *D* being the respective diameters of the two pistons. Since Pascal's Law applies to all liquids and since oil prevents

the rusting of the machine, oil is frequently used instead of water.

The fact that liquids are almost incompressible and perfectly elastic is of very great importance in connection with this machine. A pressure of 100 lb. to the square inch compresses water only .00033 of its original volume, and on the removal of the pressure, that volume is immediately restored.

The hydraulic press is largely used in such work as the compression of bales of cotton and other bulky materials for transportation on shipboard, where the space taken by a package of freight is a determining factor in the expense of carrying it.

137. Pressure Due to Gravity. — The principle stated in Pascal's Law holds whether the force employed is due to the pressure of weights placed on a piston resting upon the surface of the liquid, or to the pressure of an added layer of water. When a liquid is at a uniform temperature throughout, the entire mass is in a state of equilibrium, and there are no internal currents, as can be seen by mixing some heavy sawdust through the water. This means that *the pressure exerted by the weight of a liquid at any point in the liquid is equal in all directions.*

138. Relation of Pressure to Depth. — Since every horizontal layer of a liquid has to support the weight of the liquid above, we may write as a result the following laws:

I. *The pressure in any layer is proportional to its depth.*

II. *The pressure is the same at all points in the same horizontal layer.*

139. Vertical Downward Pressure. —When a liquid is contained in a vessel with vertical sides, the weight of each layer is transmitted undiminished to the layers below. Hence each layer bears the weight of the liquid above it, and the pressure on the bottom will be the weight of the liquid in the vessel.

Demonstration. — Screw one of the glass vessels shown in Fig. 114, into the ring of the standard. By fixing the index at any height and bringing the water to the height indicated, the pressure on the flexible base will be shown by the position of the pointer. On lowering the water supply, the water will run out of the glass vessel. Substitute a vessel of another shape. When the water surface is raised again to the fixed index, the pointer will read the same as before.

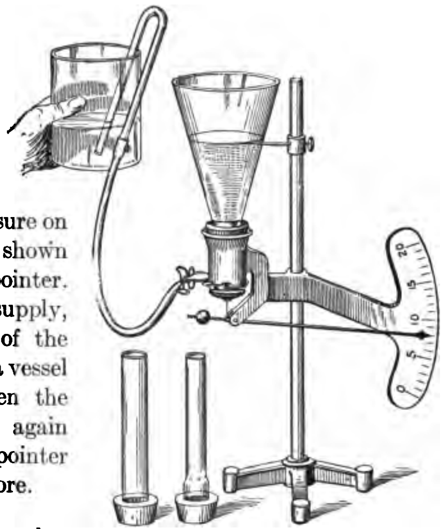


FIG. 114

The above demonstration proves that *the pressure on the bottom of a vessel containing a liquid is entirely independent of the shape of the vessel; with a given liquid it depends only upon the depth of the liquid and the area of the base.*

Demonstration. — Use salt water, which is heavier than fresh, and it will be found to require less height for the same pressure.

From this we see that *the pressure on the bottom of a vessel depends also upon the density of the liquid.*

140. Vertical Upward Pressure. — From § 138 we may infer that the upward pressure at any point below the surface of a liquid is equal to the downward pressure.

Demonstrations. — Select a glass tube, like a lamp chimney, and a glass plate or disk just large enough to cover the end of the tube. Grind the end of this tube, and the glass plate, to a water-tight joint with emery. Fasten three cords to the plate or disk, and to a

FIG. 115

single cord, as in Fig. 115. Hold the disk in place over the bottom of the tube with the cord, and push the tube down into the water in a jar. The upward pressure will hold the disk in place without the cord. Pour water into the tube until the disk falls off; then the weight of the water poured in, added to the weight of the disk, will measure the upward pressure.

Place in the bottom of a shallow pan a piece of smooth glass, and stand upon it a heavy lamp chimney of the form shown in Fig. 116, with the lower end ground smooth. Pour water into the chimney, and observe that when it rises to some definite point, *A*, it will not rise any farther because it runs out at the bottom. If the chimney is held down by placing a finger on the top and it is then filled with water, it will remain full as long as it is held down, but when the finger is removed, the water suddenly drops to *A* and stops there. What is the effect of the upward pressure of the water on the collar of the chimney in this demonstration?

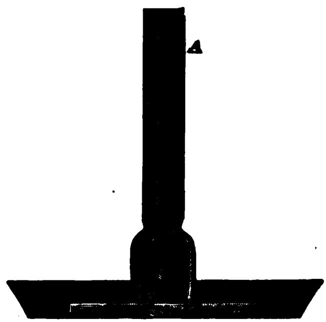


FIG. 116

141. Pressure on the Side of a Vessel. — When a liquid is contained in a vessel with vertical sides, the pressure at any point of a side depends upon its distance from the surface of the liquid. The total pressure on the sides of the vessel is the sum of all these pressures, which vary from zero at the surface to a maximum at the bottom.

The pressure of a liquid upon any submerged surface is equal to the weight of a column of the liquid having the area of the surface for its base, and the depth of the center of gravity of the given surface below the surface of the liquid for its height.

NOTE. — See § 83. In plane surfaces the center of gravity is the center of area. The center of gravity of a triangle, for instance, is a point two thirds of the distance from any angle to the mid-point of the opposite side.

The rule just given (page 134) applies to all submerged surfaces, whether vertical, horizontal, inclined, plane, or curved. If the surface is the horizontal base of the vessel, the height of the column will be the total depth of the liquid.

The law may be expressed in a formula as follows:

$$\text{Pressure} = HaW, \tag{38}$$

in which H is the height of the surface of the liquid above the center of gravity of the submerged surface, a is the area of the submerged surface, and W is the weight of a unit volume of the liquid.

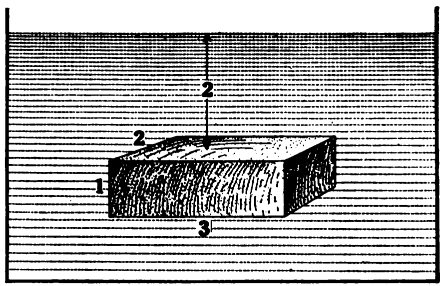


FIG. 117

A cubic foot of water weighs about 62.5 lb., or 1000 oz.

Example. — The pressure of water on any submerged body, as in Fig. 117, is found as follows:

Pressure on top (HaW) = 2 × (2 × 3) × 62.5 = 750 lb.
Pressure on bottom = 3 × (2 × 3) × 62.5 = 1125 lb.
Pressure on ends = 2 × 2.5 × (2 × 1) × 62.5 = 625 lb.
Pressure on sides = 2 × 2.5 × (3 × 1) × 62.5 = 937.5 lb.
Total pressure = 3437.5 lb.

142. Center of Pressure. — The center of pressure on a submerged surface is the point of application of the resultant of all the forces acting upon it, due to the pressure of the liquid. If we have a rectangular side to a vessel containing water, since the pressure increases from the top to the bottom,

it is evident that this point must be below the middle of the side. Calculation and experiment show that it is two thirds of the distance from top to bottom.

A convenient way to determine the position of this point is as follows. Lay off a line CB (Fig. 118) perpendicular to the side AB to represent the pressure at B. Draw the line CA. Any lines, as ED and GF, drawn perpendicular to AB, will represent the pressure at the points D and F respectively. Why?

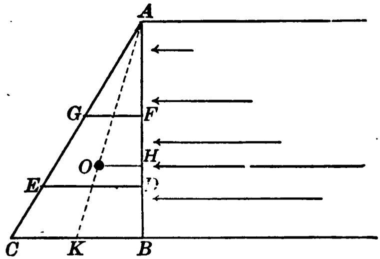


FIG. 118

The area of the triangle ABC will represent the entire pressure upon AB, and the center of pressure will be at the point H where the perpendicular from the center of area of the triangle meets the side AB. It is evident that this point will be in such a position that $AH = \frac{2}{3} AB$, since the center of gravity of ABC is at O, a point such that $AO = \frac{2}{3} AK$.

If the side AB is movable, a support at H will prevent either the top or the bottom from being pushed out.

143. The Submarine. — To be able to travel under the surface of the water as well as upon the surface, a boat must be so designed that it can be submerged at will, shall be water-tight while submerged, can be propelled while submerged, and can be brought again to the surface when desired.

To increase the weight of the boat so that it will submerge, water is let into tanks provided for the purpose. To bring the boat to the surface, the water is forced out of the tanks. Storage batteries (§ 425) supply the energy for driving the electric motors that run the propeller while the boat is submerged. Figure 119 shows the exterior of a modern submarine, and Fig. 120 gives a view of the compact interior,

FIG. 119. — Submarine as Seen on the Surface of the Water

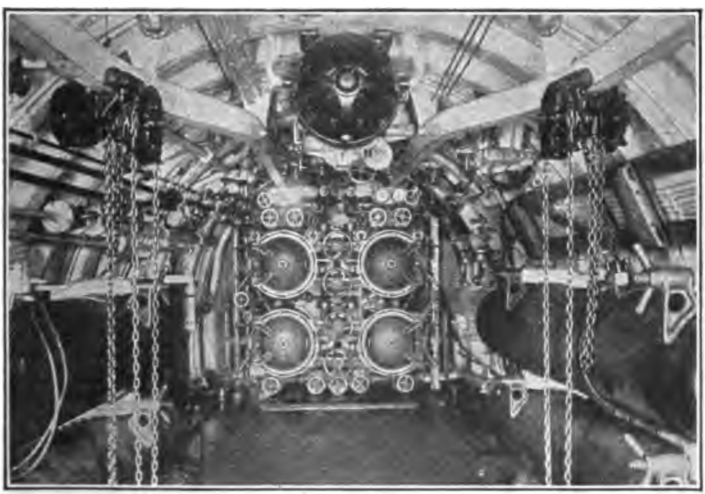


FIG. 120. — Interior of a Submarine; the Torpedo Compartment

To permit of an outlook over the surface of the water when the boat is submerged, it is provided with a periscope. This consists of an upright vertical tube leading from the interior and ending in a short horizontal piece with a lens at the end. There is a mirror at the elbow of the tube and another at the lower end that throws the image sent by the lens into the eyepiece. Figure 121 shows a periscope view looking $76\frac{1}{2}$ degrees east of north.

Fig. 121

144. The Surface of a Liquid at Rest. — We have already seen that when the resultant of all the forces that act upon any point in a liquid is zero, there will be a condition of equilibrium, and the liquid will be at rest (§ 137).

In order that the surface of a liquid may be at rest, it must be horizontal. Suppose that the surface is not horizontal, as in Fig. 122.

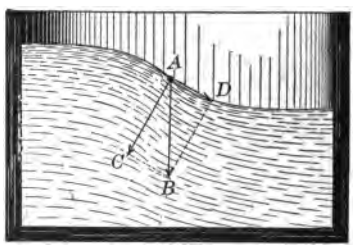


Fig. 122

The force of gravity, AB, which acts upon any molecule upon the surface, as A, may be resolved into two forces, one of which, AC, is perpendicular, and the other, AD, parallel to the surface. Now the first, AC, will be opposed by the resistance of the liquid, while the other, AD, will move the molecule to a lower level. When the surface is horizontal, the action of gravity is perpendicular to it,

and if we try to resolve this force into two components as before, we find that the component perpendicular to the surface is equal to the force, and the horizontal component is zero. Hence no movement will take place, and the liquid will remain at rest.

FIG. 123

145. Equilibrium in Communicating Vessels. — Whenever a number of vessels are connected, and water is poured into one of them, it will, when it comes to rest, stand at the same level in all. This is in direct accordance with the transfer of liquid pressure stated in Pascal's Law. Neither size, nor shape, nor position affects the result. It is in accordance with this principle that water "seeks its own level," that fountains play, and that water is distributed in city waterworks.

146. The Hydraulic Ram is used for the purpose of raising water to a greater height than its source. The machine shown in Fig. 124 uses the water from a stream or lake to force pure spring water into an elevated tank. *A* is the drive pipe connected with the water supply, a few feet above the ram. *I* is the pure water

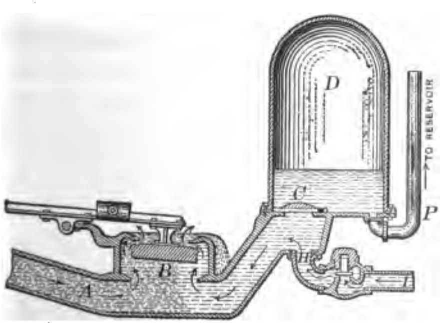


FIG. 124

pipe, and P is the service pipe which carries the water to the tank. The water flows in through pipes A and I, and out through the valve B, until the pressure due to the increasing velocity is enough to close B. When this valve closes, the momentum of the moving water produces what is called the "ramming stroke," which opens the valve C, and forces water into the air chamber D until the pressure of the air in P is equal to the pressure of the water in A. When this occurs, the flow through C is reversed, the valve closes, and the operation is then repeated.

A proper adjustment of the quantities of water in A and I respectively must be made so as to insure that only pure water can flow into D. If the water coming down A is pure enough to be sent into the tank, I is removed, and H is closed with a screw plug.

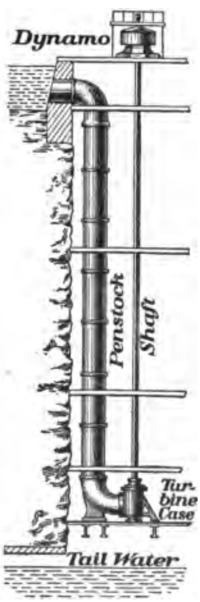


FIG. 125.—A Turbine at Niagara Falls

147. The Turbine Water Wheel is another, more important, machine for utilizing the pressure of a column of water. The well-known form of lawn sprinkler which throws water in small streams from holes in one side of each of four revolving arms, is a simple *reaction turbine*. The rotation is produced by the reaction of the air and the difference in pressure on the opposite sides of the tube. A jet of water directed against the paddles of a paddle wheel so as to make it rotate by the force of the impact would illustrate the principle of an *impulse turbine*. Both principles are used in turbine water wheels, which are made in various forms.

At Niagara Falls water goes from the vertical penstock into the central part of a horizontal wheel and passes outward between fixed guides, *G*, Fig. 126, which direct it against the vanes *V* attached to the rotating part of the wheel. The motion may be produced either by the impact upon *V* in the direction of the heavy arrow, or by the reaction as the water leaves the wheel in the opposite direction. The wheel rotates a vertical shaft connected with the dynamo at the top of the wheel pit (Fig. 125).

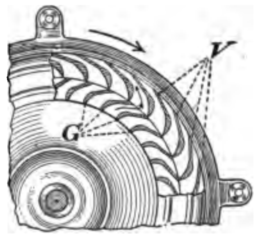


FIG. 126

In another type of turbine, the water enters the outer part of the wheel through fixed guides, and leaves the inner part through moving vanes.

Questions

1. Why do liquids exert pressure on submerged surfaces? What governs the amount of this pressure?

2. State the rule for finding the pressure on any submerged surface.

3. State Pascal's Law.

4. Name the essential parts of a hydraulic press.

5. State the law of the hydraulic press. Can oil be used to operate it as well as water?

6. If the areas of the large and small pistons of a hydraulic press are to each other as 20 is to 2, how would the total pressures exerted on each compare? How would the pressures per square inch on each compare? How would the distances moved through by each compare?

7. Why would not air answer so well as water in a hydraulic press?

8. Why is a dam built with the base thicker than the top? Why is the upper face usually made slanting up stream?

9. What determines the pressure at the nozzle of a fire hose when it is connected directly to the hydrant?

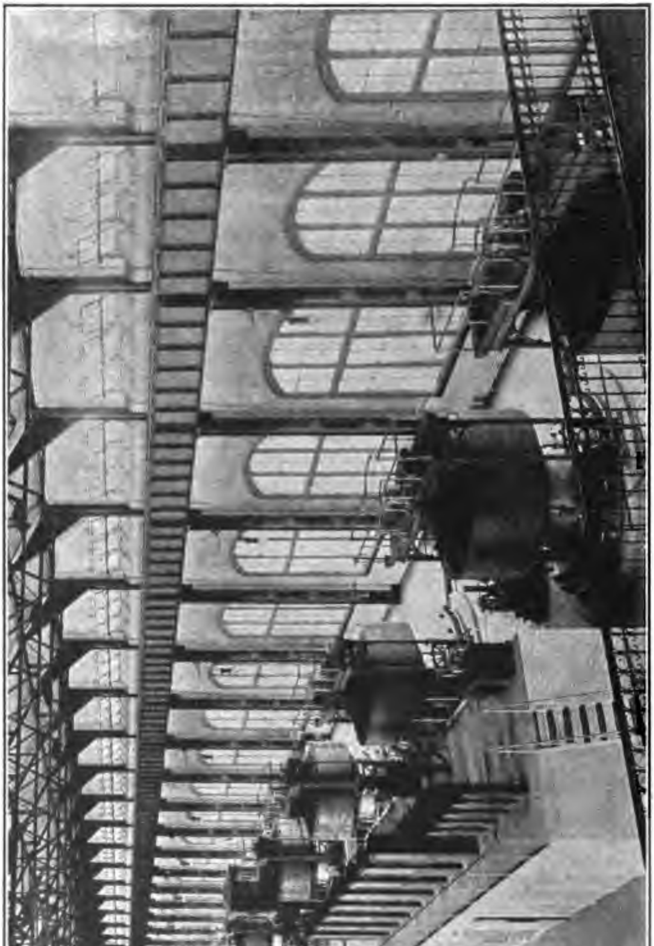


Fig. 127. — Dynamos run by Turbines at Niagara Falls

10. If oil and water are shaken together in a test tube and it is then set aside, what will happen? Why?

11. Why is an air chamber used in a hydraulic ram?

12. What is the direction of the pressure of water on the walls of the vessel that contains it?

13. A hole 2 ft. long and 1 ft. wide is broken in the side of a ship. What would be the result of weighting a piece of heavy sail cloth with a piece of iron at each of the two corners and letting it down the side of the ship over the hole?

Problems

1. The area of the large piston of a hydraulic press is 300 sq. in., that of the small piston is 12.5 sq. in. What pressure is delivered by the large piston when a force of 580 lb. is applied to the small piston?

2. What must be the area of the large piston of a hydraulic press in order that a force of 178 lb. applied to the small piston, the area of which is 0.48 sq. in., will raise a load of 2000 lb.?

3. The small plunger of the hydraulic press shown in Fig. 113 is 2 in. in diameter and the large plunger is 14 in. in diameter. What upward pressure on B will a power of 30 lb. exert if the lever is 3 ft. long and the distance from the plunger to the fulcrum is 5 in.?

4. The diameter of the large cylinder of a hydraulic press is 30 in., that of the small cylinder 1 in. What is the pressure exerted by the large piston when a force of 100 lb. is applied to the small piston?

5. The pistons of a hydraulic press are respectively $\frac{1}{2}$ in. and 24 in. in diameter. What pressure must be used on the small piston to produce a pressure of 40,000 lb. on the large piston?

6. Find the pressure on the bottom of a tank 18 ft. long and 7 ft. wide when filled with water to a depth of 4.5 ft.

7. What is the pressure on the bottom of a tank 8 cm. long, 5 cm. wide, and 4 cm. deep when filled with water? When filled with mercury, the weight of which is 13.6 g. per c.c.?

8. What is the pressure against one end of a swimming pool 60 ft. long, 25 ft. wide, and 9 ft. deep? What would the pressure be if the length were only 40 ft.?

9. What is the pressure in pounds per square inch in a water pipe 230 ft. below the surface of the water in the reservoir?

Fig. 128

10. The steel water tank shown in Fig. 128 has an internal diameter of 22 ft. The height of the cylindrical portion is 28 ft., and the bottom is a hemisphere. When the tank is full, the water surface is 100 ft. above the ground. How many gallons does the tank hold?[1] What is the vertical pressure on the bottom? What is the pressure on the cylindrical side? What is the pressure per square foot at the bottom of the feed pipe?

11. An hydraulic elevator with a plunger 8 in. in diameter is connected with water works having a head of 186 ft. What is the lifting power of the water upon the plunger in the elevator well? If the elevator, with plunger, weighs 1700 lb. more than its counter-weight, how many people averaging 150 lb. each, can it carry?

12. At the depth of 100 ft., what is the pressure on each square foot of the surface of a submarine, sea water being 1.025 times as heavy as fresh water?

13. Find the pressure in grams against a stopper 5 sq. cm. in area placed in a hole in the side of a tank of mercury with its center 35 cm. below the surface.

14. The two leaves of a lock gate are each 12 ft. long and 15 ft. high. What is the pressure on each when the lock is filled with fresh water?

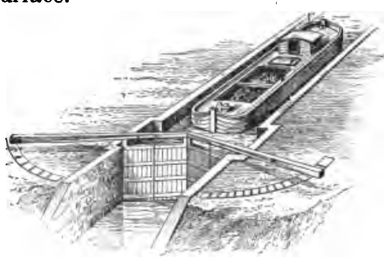


Fig. 129. — Lock Gate

15. What is the pressure per square inch of the water striking the blades of a turbine water wheel when the head of water is 48 ft.?

16. Where is the center of pressure on a dam 24 ft. long and 12 ft. high?

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[1] Vol. of cylinder = $\pi r^2 \times H$. Vol. of sphere = $\frac{4}{3}\pi r^3$. 1 gal. = 231 cu. in.

FIG. 130.—A Lock in the Panama Canal

17. Where is the center of pressure on the leaves of the lock gate mentioned in problem 14?

18. A box 1 m. long, 80 cm. wide, and 60 cm. deep is filled with water. Find the pressure on the bottom, sides, and ends in kilograms.

19. An air-tight wooden box 60 cm. long, 50 cm. wide, and 40 cm. deep is weighted so that it sinks to the bottom of a pond 6 m. deep. Compute the pressure with which the water tends to crush the box.

III. SPECIFIC GRAVITY

148. The Principle of Archimedes.— Demonstrations. — Tie a strong thread to a stone, suspend the stone from a spring scale, and note its weight. Weigh again, letting the stone hang in a beaker of water, and the scale will be found to read less. Why?

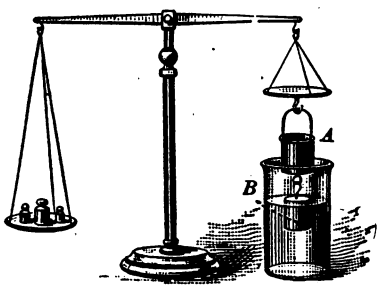


FIG. 131

Suspend from one side of a balance a short brass tube *A* (Fig. 131), and from a hook in the closed bottom of this tube suspend a solid cylinder *B*, which will just fill the tube. Put weights upon the other scale pan until the beam is horizontal. Immerse *B* in water, and the equilibrium will be destroyed. Fill *A* with water, and the equilibrium will be restored.

We learn from the above, both that a body *appears* to lose weight when it is immersed in a liquid, and that *the amount of this apparent loss is exactly the weight of the water displaced.* The fact that a submerged body seems to weigh less in a liquid than in the air was observed by the Greek philosopher Archimedes in the third century B.C. He not only observed the apparent loss of weight, but discovered the

exact law governing it, hence the law is called the *Principle of Archimedes.* It may be stated as follows:

A body immersed in a liquid is buoyed up by a force equal to the weight of the displaced liquid.

This tendency of a liquid to lift a submerged body is called its *buoyancy,* and depends in amount upon the density of the liquid and the size of the body.

Since weight is the measure of the mutual attraction between the earth and the body weighed, there can be no real loss of weight, when a body is submerged in water. If, however, we suspend the body by means of a spring scale and weigh it in the air and then weigh it again in water, there will be a decrease indicated on the scale, and it is this decrease that is often called loss of weight.

If a body, a cube for instance, is immersed in a liquid, the horizontal pressure acting upon any side will be exactly counterbalanced by the pressure upon the opposite side. The downward pressure upon the upper surface *A* will be equal to the weight of a column of water having for its base the area of *A*, and for its height the depth of *A* below the surface of the water. The upward pressure upon the lower surface *B* will be equal to the weight of a column of water having for its base the area of *B*, and for its height the depth of *B* below the surface of the water. The difference between these pressures is the buoyancy of the liquid, and is equal to the weight of a quantity of the liquid that has the same

FIG. 132

volume as the submerged cube. This conclusion is verified by the result of experiment.

149. Floating Bodies. — When a body is placed in a liquid, the position it finally takes will depend upon the relative densities of the body and the liquid. If a stone or a drop of mercury is placed in water, it will sink, since it is heavier than the water. If a drop of olive oil is placed in a mixture of alcohol and water, of the same density as itself, it will remain wherever it is placed. If a piece of wood is placed in water, it will rise to the surface and float. The Principle of Archimedes applies to each of these cases, however, and we may write this *Law of Floating Bodies:*

FIG. 133

A floating body displaces a volume of liquid that has the same weight as the floating body.

Demonstration. — Make a bar of pine wood 25 cm. long and 1 cm. square. Bore a hole in one end and run in molten lead. Divide off one side of the bar into centimeters. Cover the bar with melted paraffin, melting it into the pores of the wood over a flame. Float the bar upright in a tall jar of pure water (Fig. 133); then, since 1 cc. of water weighs 1 g., the reading of the height at which it floats will give the approximate weight of the bar in grams.

150. Density. — The quantity of matter, or the mass, in a unit volume measures the *density* of a substance. If a piece of lead, for example, has a mass of 45.4 g. and a volume of 4 cc., then the density of this lead equals $45.4 \div 4 = 11.35$ g. per cubic centimeter. The general expression is

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}.$$

Hence, *masses of equal volumes are directly proportional to their densities*, and *volumes of equal masses are inversely proportional to their densities.*

The *relative density* of a substance is the ratio of its density to the density of pure water at a temperature of 4° C. If we assume the quantity of matter in 1 cc. of pure water at 4° C. as a unit of density, the density of the water will be 1, and the quantity of matter in 1 cc. of any other substance will measure its relative density.

The density of water varies with its temperature as well as with its purity. The temperature 4° C. is taken for the standard density because the density of water is greatest at that temperature. In order to get the most accurate results in the following experiments, distilled water at 4° C. must be used.

151. Specific Gravity. — Since the ratio between the weights of equal volumes of substances in the same place is the same as the ratio of their masses, we can use the term *specific gravity* in place of *relative density*. Since, also, pure water is taken as the standard in specific gravity, we may express it by the following formula:

$$\text{Sp. gr.} = \frac{\text{Weight of the body in air}}{\text{Weight of an equal volume of water}},$$

or $$\text{Sp. gr.} = \frac{\text{Weight of the body in air}}{\text{Buoyant force of water displaced}},$$

or $$\text{Sp. gr.} = \frac{W}{W - W'}. \tag{39}$$

In this expression W is the weight of the body in air, and W' its apparent weight in water.

Since there are different systems of weights and measures it is evident that the number representing the density of a substance will depend upon the system of units used, while its relative density or its specific gravity will be the

same in all systems. For example, the density of wrought iron in the C. G. S. system is 7.85, which means that it has a mass of 7.85 g. per c. c. In the F. P. S. system its density is 489, which means that its mass is 489 lb. per cubic foot. In both systems its specific gravity is 7.85, which means that its weight is 7.85 times that of an equal volume of water.

The density of a substance depends upon its physical condition. If the substance is a mineral, its density depends upon its purity. If the substance is a metal, its density is affected by the treatment received in the process of manufacture; for instance, whether it is cast, or drawn into wire. The density of an alloy depends upon the proportional parts of the metals composing it.

The accompanying table of densities and specific gravities is made by taking the average of results found by different observers. With

	Density in g. per c.c. = Sp. Gr.	Density in lb. per cu. ft.		Density in g. per c.c. = Sp. Gr.	Density in lb. per cu. ft.
Charcoal (oak)	0.57	35.	Iron (gray cast)	7.08	442
Butter	0.86	53.	Zinc (cast)	7.10	443
Paraffin	0.89	55.5	Tin (cast)	7.29	455
Ice	0.917	57.3	Iron (wrought)	7.85	489
Beeswax	0.96	60.	Brass (yellow)	8.44	527
Sandstone	2.35	146.5	Brass (red)	8.60	536
Feldspar	2.55	160.	Nickel	8.60	536
Aluminum (cast)	2.57	160.5	Copper (cast)	8.88	553
Glass (common)	2.60	162.5	Silver (cast)	10.45	652
Quartz	2.65	165.	Lead (cast)	11.34	708
Marble	2.65	165.	Mercury	13.596	848
Granite	2.75	171.	Gold (cast)	19.30	1205
Garnet	3.70	232.	Platinum	21.45	1338

slight exception they are as reported in the Physical Tables published by the Smithsonian Institution.

152. To find the Specific Gravity of a Body Heavier than Water. — Tie a light cord about the body, suspend it from one arm of a balance, and weigh it; call this weight W. Weigh again with the body suspended in water, as in Fig. 134. Call this apparent weight W'. Substitute these values in Formula 39, and the result will be the specific gravity of the body.

FIG. 134

EXAMPLE. — The weight of a stone in air (W) = 146 g.
Its apparent weight in water (W') = 94 g.

Since the specific gravity is the weight of the stone divided by the weight of an equal volume of water and since the difference between the weight of the stone in air and in water is the buoyant force of the water, or the weight of a volume of water equal to that of the stone:

$$\text{Sp. gr.} = \frac{146}{146 - 94} = \frac{146}{52} = 2.8.$$

153. To find the Specific Gravity of a Body Lighter than Water. — Since the buoyant force of the water is greater than the weight of the body, it will float, and it must be fastened to a heavy body in order to submerge it. The specific gravity can be found as follows:

Weigh the body in air (W), then weigh a heavy sinker in water and call its apparent weight S. Tie the sinker

to the body and weigh them both in water. Call the apparent weight W''. Compute the specific gravity from the formula Sp. gr. $= \frac{W}{W + (S - W'')}$.

Example. — Suppose a piece of wood weighs 40 g. in air (W), a sinker registers 50 g. in water (S), and the two when tied together and submerged register 30 g. (W''). It is evident that the wood not only displaces its own weight of water, but buoys up 20 g. of the weight of the sinker; therefore the wood displaces 40 + 20 g. of water, hence its specific gravity is $\frac{40}{40 + (50 - 30)} = \frac{40}{60} = .67$.

154. To find the Specific Gravity of Liquids. — (*a*) *By the Specific Gravity Bottle.* — Any bottle with a small neck having a fixed mark around the neck can be used in this method. Weigh the bottle when empty (a). Fill with water to the fixed mark and weigh (b). The difference gives the weight of water ($b - a$). Fill with the required liquid and weigh (c). The difference ($c - a$) gives the weight of the same volume of the liquid. Then the specific gravity will be $\frac{\text{Weight of liquid}}{\text{Weight of equal volume of water}} = \frac{c - a}{b - a}$.

Example. — Weight of the empty bottle (a) = 54 g.
Weight of the bottle filled with water (b) = 304 g.
Weight of the bottle filled with the liquid (c) = 252.25 g.

$$\text{Sp. gr.} = \frac{c - a}{b - a} = \frac{252.25 - 54}{304 - 54} = \frac{198.25}{250} = .793.$$

Specific gravity bottles are usually made to hold a certain number of grams of water at a stated temperature, and are so marked.

If the bottle holds 1000 g. of water, the specific gravity can be obtained directly. For example, if a thousand-gram

bottle holds 1240 g. of hydrochloric acid, then the specific gravity of the acid is 1.240.

(*b*) *By the Method of Balancing Columns.* — A good form of apparatus for this method is that of Hare, shown in Fig. 135. *A* and *B* are glass tubes joined at the upper ends to the branches of a Y tube. The other end of the Y is joined to a rubber tube *R*. The lower end of each tube dips into a liquid in a beaker. *C* is a clamp and *M* a meter stick. When pressure is reduced in *R* the liquids rise to heights that are inversely proportional to their specific gravities. If water is in *A* and alcohol in *B*, the specific gravity of the alcohol will be as follows:

$$\text{Sp. Gr.} = \frac{\text{Height of } A}{\text{Height of } B},$$ the heights to be measured from the surface of the liquid in each case.

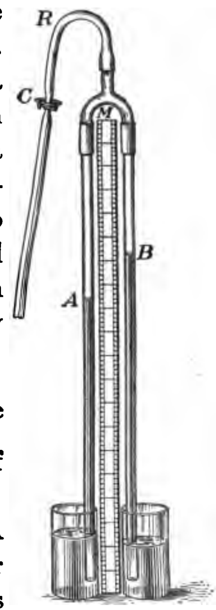


FIG. 135


FIG. 136

(*c*) *By the Hydrometer.* — A constant-weight hydrometer usually consists of a small glass tube to which two larger bulbs are sealed. Either mercury or small shot are put into the lower bulb in order to keep the stem of the instrument vertical. For liquids heavier than water the unit mark is placed at the upper end of the stem, which is graduated decimally. This instrument (Fig. 136) is used by floating it in the liquid in a hydrometer jar, and reading the height to which the liquid stands on the stem.

Special forms of hydrometers are used for special liquids.

The *alcoholmeter* is used for determining the percentage of absolute alcohol in spirits, and the *lactometer* for testing the purity of milk.

Questions

1. Why do liquids buoy up objects immersed in them?

2. What governs the amount of this buoyant effect?

3. Why do some objects float on water while others sink?

4. State the law governing the buoyant effect of liquids on bodies immersed in them. State the law for floating bodies.

5. Why is not a submerged body pushed sideways by the pressure of the water when submerged in it?

6. Define density; specific gravity.

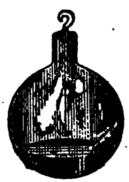


Fig. 137

7. What is taken as the unit in specific gravity? Why?

8. Suppose you weigh a glass bulb loaded with mercury, like Fig. 137, first in air, then in water, and then in kerosene. How would you find the specific gravity of the kerosene?

9. Why does a hydrometer float vertically in a liquid?

10. Where is the unit mark placed on a hydrometer that is to be used for liquids lighter than water? Why?

Problems

1. A boy can lift 100 lb. How many cubic inches of granite, the sp. gr. of which is 2.75, can he lift? How many cubic inches of granite can he lift in water?

2. A block of wood 1 ft. square and 2 ft. long is pushed down into the water until its upper side is 6 in. below the surface. What is the upward pressure upon the bottom of the block? What is the downward pressure of the water on the top of the block? How much pressure is required to keep the block in place, if its specific gravity is .65? How much pressure would be required to keep it at a depth of 2 ft.?

3. An automobile weighing 3600 lb. is ferried across a river on a flatboat. How much deeper is the boat in the water after the

automobile is on board than before, if the boat is 18 ft. long and 10 ft. wide?

4. Ice forms 16 in. thick over the surface of a lake. What is the weight of a cake 2 ft. long and 18 in. wide? How much of its thickness will be above the water when it floats?

5. An iceberg 80 ft. thick cracks off from a glacier and floats away into the sea. How high does it stand above the water surface?

6. A cake of ice 6 ft. square and 2 ft. thick is floating on a lake. How much will it settle in the water if a man weighing 180 lb. stands upon it?

7. A river scow 60 ft. long, 22 ft. wide, and 5 ft. out of water when empty is loaded with coal until the top of the boat is within 6 in. of the surface. How many tons of 2240 lb. each in the load?

8. A block of sandstone 6 cm. long, 4 cm. wide, and 2 cm. thick weighs 112.8 g. What is its density in grams per cubic centimeter?

9. A block of nickel weighs 86 g. in air and has a volume of 10 cc. What is its specific gravity? What is its density?

10. A piece of anthracite coal weighs 80 g. in water and has a volume of 120 c.c. What is its specific gravity? What is its weight in air?

11. The metal from which the United States Standard Meter is made is 90 % platinum and 10 % iridium and weighs 1348 lb. per cubic foot. What is its density in grams per cubic centimeter?

12. An ordinary brick is 8 in. long, 4 in. wide, and 2 in. thick and weighs 5 lb. What is its apparent weight when submerged in water?

13. A boy agreed to carry a gallon (231 cu. in.) of mercury across the room. How much did he have to lift?

14. A glass stopper weighs 162 g. in air and has an apparent weight of 100 g. in water. Find its specific gravity and the density of glass in pounds per cubic foot.

15. A piece of sandstone had an apparent weight of 168 lb. when submerged in water. When lifted from the water it weighed 293 lb. What was its volume?

16. A cast iron machine frame weighing two tons fell overboard in a canal. How great a pull will be required to bring it from the bottom to the surface of the water? How much greater must the pull be to lift it in the air?

17. A block of metal, having a volume of one cubic decimeter, is suspended from the hook of a spring balance and its reading noted. It is then lowered into water until it is half submerged. What is the change in the reading of the balance?

18. A piece of platinum 2 c.c. in volume was suspended from a spring scale and its weight noted. It was then lowered into mercury. What was the weight of the platinum in air? What was its apparent weight in mercury?

19. A piece of iron bar weighed 94 lb. in air and 82 lb. in water. What kind of iron was it and how many cubic inches did it contain?

20. A block of wood weighing 125 g. in air was tied to a sinker which weighed 100 g. in water. On being weighed together in water the weight was 63 g. What was the specific gravity of the wood?

21. A bottle weighing 236 g. was filled with water and then weighed 486 g. On being filled with olive oil it weighed 465 g. What was the specific gravity of the oil?

22. A bottle with stopper and pinchcock weighs 350 g. After most of the air in it has been pumped out it weighs 348.341 g. The pinchcock is then opened under water, and when water has taken the place of the air removed by the pump, the bottle and contents weigh 1631.591 g. What was the density of the air?

23. A column of water in one branch of the tube shown in Fig. 135 read 129 cm. while a column of milk in the other branch read 125 cm. What was the specific gravity of the milk?

24. A column of water was balanced in the same piece of apparatus by a column of turpentine. The water stood at 22 cm. and the turpentine at 25 cm. What was the specific gravity of the turpentine? What was its density per cubic foot?

25. A cubic foot of granite weighed 171 lb. in air. It was then weighed when submerged in turpentine. What was its apparent weight?

CHAPTER V

GASES

155. Gases and Vapors. — A *gas* is matter in such a condition that it has a tendency to expand indefinitely. Gases have no independent shape, but take the form of the vessel in which they are confined. Great pressure and a low temperature are required to change most gases into the liquid state. The name *vapor* is given to gaseous matter that is liquid or solid at normal temperatures and pressures. Water vapor is an example of vapor, while atmospheric air is a familiar form of gas, and will be used in studying the phenomena and properties of gases.

156. Expansibility. — **Demonstration.** — Put a rubber bag — a toy balloon will answer — under the receiver of an air pump, having first blown a little air into it and tied the stem. Exhaust the air, and the balloon will be seen to increase in size. It will do this as long as air is pumped from the receiver.

FIG. 138

This expansion of the air is best explained by the *kinetic theory of gases* (§ 6): The molecules of a gas are in rapid motion in straight lines, and they continue to move in their paths until turned aside by striking either other molecules or the side of the containing vessel. When the balloon is put under

the receiver of the air pump, the number of molecules of air per cubic centimeter is the same inside it as outside of it, and the bombardment of the molecules on one side neutralizes that on the other, so the walls of the bag remain as they are. As soon as air is taken from the receiver, however, the number of molecular blows on the inside exceeds the number on the outside for the same surface, and the bag is stretched out until they are equal. This means that there are again the same number of molecules in the same space both inside and outside, or, the density is the same. If now the air is let into the receiver, the blows on the outside increase and the bag shrinks to its original size, beaten down by the impact of the molecules of the outside air. The combined effect of the impact of the molecules of air inside the bag makes up the internal pressure of the air.

157. Compressibility. — In order to show the great compressibility of gases, it is only necessary to apply force to an air-tight piston moving in a cylinder closed at one end. It can be shown in a very simple way by pushing the open end of a long test tube below the surface of water. It will be found that the deeper the tube is thrust into the water, the higher the water rises within it; and the more the air is compressed, the greater is the pressure required to force the tube into the water.

158. Elasticity. — Gases are not only compressible, but perfectly elastic under compression.

Demonstration. — Raise the piston of a bicycle pump to the top, then close the tube leading from the pump and force the piston down. A sharp push will bring it nearly to the bottom, showing a compression of, say, nine tenths. Now let the piston go, and it will rise again to the top of the pump.

The elasticity of gases differs from that of solids in that it is elasticity of *volume* and not of *form*. Gases are said to be perfectly elastic because they have no elastic limit (§ 17); but their elasticity is not very great as measured by Formula 1.

159. The Air Pump is an instrument used for removing the air from any vessel with which it is connected. The possibility of doing this depends entirely upon the fact that air is elastic. A simple air pump consists of a cylinder *A*

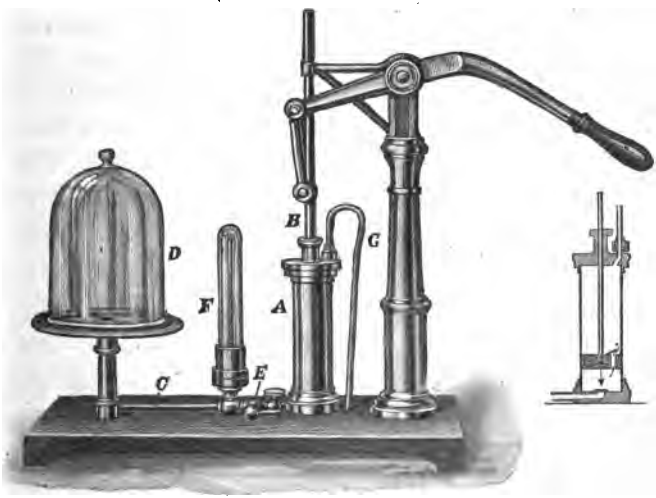


FIG. 139. — Air Pump

(Fig. 139), in which moves a piston attached to the rod *B*. A tube *C* connects this cylinder with a receiver *D*, from which the air is to be removed. There are two valves between the air in *D* and the external air: one in the base of the cylinder, and the other in the piston. These open upward, allowing the air to move in one direction only.

At E there is a stopcock so arranged that it will permit free passage for the air between the pump and the receiver, or cut the receiver off altogether. F is an air-tight glass tube which communicates with the receiver, and contains a closed manometer (see § 179, b) for measuring the degree of exhaustion.

The operation of the air pump is as follows: Suppose the piston to be at the top of its stroke. The first movement downward will slightly compress the air under it. This closes the valve at the base of cylinder A and opens the valve in the piston. The air passes through this valve, and when the piston is at the bottom of its stroke, the air in the cylinder is above it. As soon as the piston is raised, the pressure below it is decreased and the valve is closed, and as the piston rises, the air is forced out of a hole in the top of the cylinder, or through the small tube G. The cylinder below the piston is filled with air expanding from D. Each stroke is only a repetition of the first, except that the amount of air taken out diminishes with every stroke.

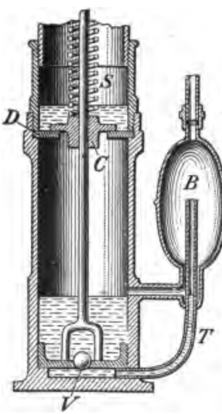


Fig. 140

160. The Fleuss Pump. — One of the most satisfactory mechanical air pumps is the Fleuss or Geryk pump, a diagram of which is shown in Fig. 140, while Fig. 141 shows the pump itself. The cylinder is separated into two compartments by a diaphragm D. There is an opening in this diaphragm, which is closed by a collar C, through which passes the piston rod, forming an air-tight joint. The collar is kept down by the pressure of a spring S, and the lower part of each compartment is filled with a heavy oil. When the piston is raised, the valve V

closes, the oil above it is raised and the air compressed, until the shoulder on the piston strikes C and raises it, when the air and a part of the oil pass through into the upper chamber. When the piston is lowered, a part of the oil runs back to the lower compartment, but the air, being above the oil, cannot run through. The chamber B is connected to the space from which the air is to be exhausted. The tube T connects B with the cylinder below the piston, thus preventing the formation of a vacuum there when the piston rises. The oil makes the valves air-tight, so that this pump is easy to work and of high efficiency.

FIG. 141. — Fleuss Pump

161. Uses of the Air Pump. — There are many practical uses of the air pump, among them its application to "vacuum pans" for the making of sugar, in which the pressure is kept low, so that evaporation will take place at a lower temperature and the sugar will not be burned. Another important use of the air pump is in the manufacture of incandescent lamps and thermos bottles.

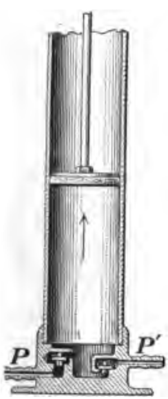


FIG. 142
Rev.

162. The Condensing Pump.—If the valves in the pump shown in Fig. 139 were arranged to open downward instead of upward, the pump would be a condenser. When it is necessary, however, to transfer a gas from one vessel to another, an arrangement like that

shown in Fig. 142 is used. In this pump the piston head has no valve. The pipe P is attached to the gas supply, and the valve in P opens *toward* the cylinder. The pipe P' is attached to the vessel in which the gas is to be compressed, and its valve opens *away* from the cylinder.

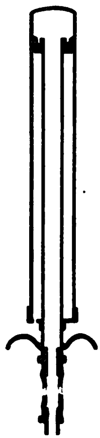
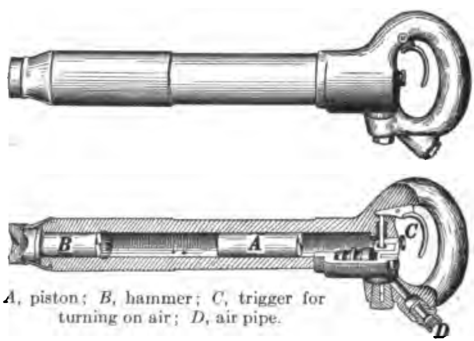


Fig. 143

The valveless bicycle pump, Fig. 143, consists of a tube, to one end of which there is fixed a piston head carrying a concave leather collar. When the cylinder is drawn back, the air passes around the collar, but when it is pushed forward the collar fills the cylinder, the air is compressed, and passes through the tube into the tire.

163. Uses of Compressed Air.—Pascal's Law of the equal transmission of liquid pressure may be applied to gases as well; hence compressed air may be applied to the transmission of power. There are many machines in which a practical application of such transmission is used. Riveting hammers are used for forming the rivet heads on steel work. Pneumatic tools are also used in stone cutting, calking the seams of ships and the joints of water pipes, iron chipping, drilling, and the like. Rock drills, sand blasts for cleaning metal surfaces, railroad signal



A, piston; *B*, hammer; *C*, trigger for turning on air; *D*, air pipe.

Fig. 144. — Riveting Hammer

operation, and submarine work are other common applications of the use of compressed air.

164. The Gas Holder. -- An important application of the transmission of pressure by gases is made in the transmission of the gas itself in the delivery of illuminating gas from the gasometer, or gas holder, to the delivery pipes. Figure 146 shows how this is done and gives a cross section of the gas holder, which consists of an inverted bowl of steel, the edge of which dips below the surface of water. Pumps force the gas into the holder from the retorts where it is made. Since the holder is supported by the gas underneath it, the weight of the holder produces the pressure that forces the gas through the service pipes.

The sections of the holder work within one another somewhat like the sections of a telescope. A circular trough is bolted on the outside of the upper section at its lower edge (Fig. 146) and is filled with water. An inverted trough is fastened to the inside of the next section below at its upper edge in such a way that when the upper section is filled with gas and rises, the two sections are coupled together by the lips of the troughs, which form a water seal (Fig. 145).

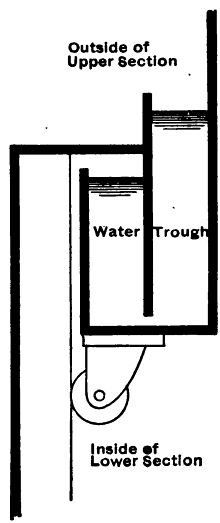


FIG. 145.—Cross Section of Water Seal

When the weight of the second section is added to that of the first, the pressure on the gas is increased; a governor is therefore placed in the delivery pipe to equalize the pressure. The weight of the upper section must

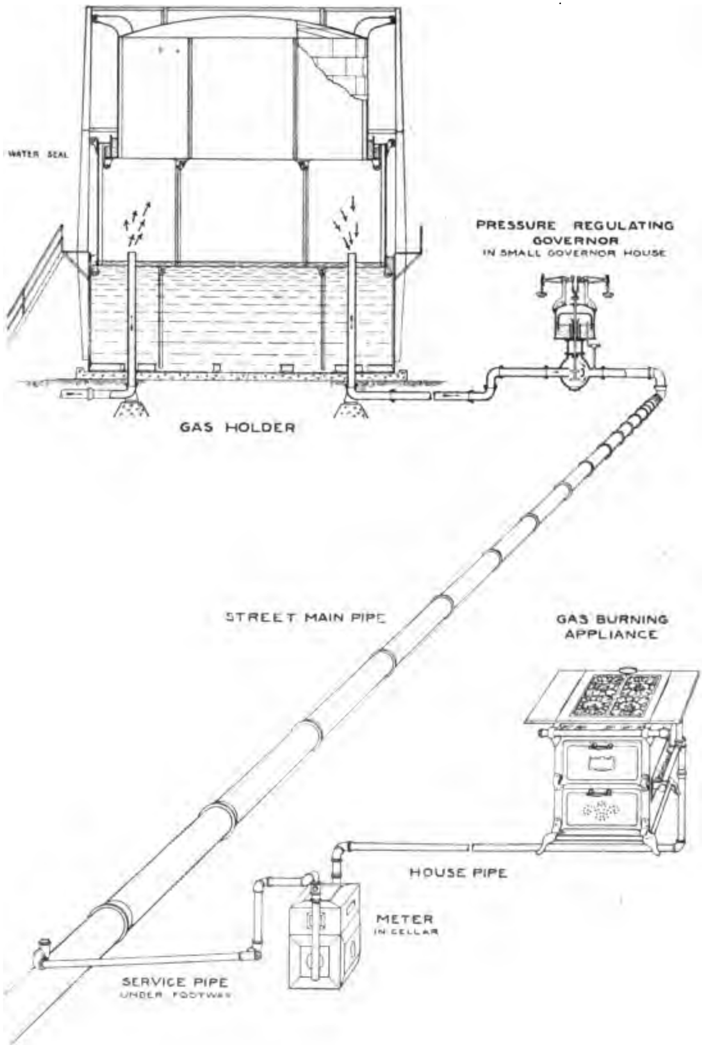


Fig. 146. — Diagram of a Gas Supply System

be great enough to give the required pressure to the gas when the other sections are not in use.

165. Weight. — Though gases are the lightest forms of matter, each has weight, as may be found by weighing.

Demonstrations. — Weigh on a delicate balance a light glass flask that is fitted with a stopcock. Exhaust the air from the flask and weigh it again, and the flask and contents will be found to be lighter than before.

FIG. 147

Weigh carefully an incandescent lamp bulb. One with a broken filament will answer, and one with a light base is desirable. Direct the point of a blowpipe flame upon one side of the bulb. As soon as the glass becomes red-hot it is forced in by the pressure of the atmosphere, and if only the point of the flame is used, a small, round hole will be blown in the bulb. The filament will probably be blown in pieces, but the pieces will all be inside the bulb, and there will be no loss of weight on account of losing any of them. Weigh the bulb a second time, and the difference in weight will be the weight of the air that has entered the bulb.

By an extension of these methods the weight of air and other gases has been found. The weight of 1 c.c. of dry air at 0° C. and the barometric pressure of 760 mm. is 0.001293 g. Since 1 c.c. of water at 0° C. weighs practically 1 g., the weight of air is $\frac{1}{773}$ of the weight of water.

Hydrogen, the lightest known gas, weighs 0.0000899 g. per cubic centimeter; hence air is about 14.4 times as heavy as hydrogen. The weight of air in English measure is 0.33 grain per cubic inch, of hydrogen 0.0228 grain, and of carbon dioxide 0.5046 grain.

166. Composition of the Atmosphere. — The air composing the atmosphere of the earth is a mixture of gases. About $\frac{1}{5}$ by volume is oxygen, $\frac{4}{5}$ nitrogen, $\frac{1}{2500}$ carbon dioxide, and a variable proportion aqueous vapor.

The quantity of aqueous vapor depends greatly upon the temperature; it varies from 4.835 g. or less per cubic meter at 0° C., to 22.796 g. or less per cubic meter at 25° C.

Besides the above, there are traces of other common gases, as ammonia and ozone, and small quantities of several recently discovered gases. Argon was discovered in 1895 by Lord Rayleigh and Professor Ramsay as the result of an admirable course of scientific research. It forms nearly $\frac{1}{100}$ of the atmosphere. After its discovery, Professor Ramsay continued his researches, and discovered four other gases in the atmosphere, — helium, neon, krypton, and xenon. These are present in minute quantities only, and are isolated by the employment of low temperatures.

167. Pressure of the Atmosphere. — Since air has weight, the layers of air near the surface of the earth are subject to a pressure due to the weight of the air above.

Demonstrations. — Tie a sheet of thin rubber over one end of a bladder glass (Fig. 148) and place it on the plate of an air pump. Remove a part of the air below the rubber by a stroke or two of the pump. The rubber will be pushed inside the glass. What supports the downward pressure of the air before the pump is worked?

Fig. 148

Cut off the stem of a thistle tube about 4 in. from the cup. Tie a thin rubber sheet over the cup. Slip over the stem a flexible rubber tube, and draw out some of the air by suction. Pinch the rubber tube to keep the pressure constant. Hold the cup in different positions (Fig. 149), and it will be seen that the air presses equally in all directions.

Fill a tumbler full of water. Slide a heavy card over the top of the tumbler, being careful that no air bubbles are left below it. Hold the card while you invert the tumbler. Remove the support from the card, and it will remain pressed against the tumbler, holding in the water. Hold the card on and turn the tumbler so that the card is vertical; when the hand is removed, the card still remains.

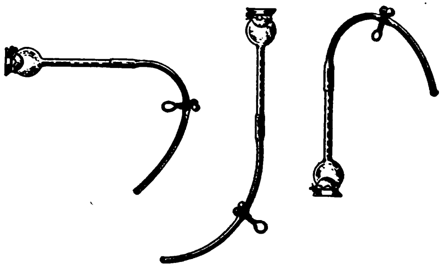


FIG. 149

Select a long, clear glass bottle and fit to the neck a rubber stopper with one hole. Pass through this a short glass tube with the inner end drawn down to a fine opening. Fit one end of a rubber tube to the outer end of the glass tube and connect the other end to the air pump. Exhaust the air. Pinch the tube together; hold the bottle as in Fig. 150, and pull the rubber from the glass tube when it is below the surface of the water in the dish *A*. The pressure of the air upon the surface of the water will force a stream through the tube, forming a fountain inside the bottle, and the water will continue to flow until the amount of water in the bottle is equal to the volume of air taken out. This is a very old experiment, called the *fountain in vacuo*.

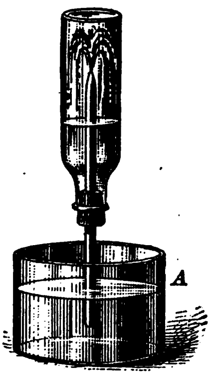


FIG. 150

Procure two small bottles and put into each the end of a U-tube, fitting loosely in *B* (Fig. 151), and air-tight through a rubber stopper in *A*. Fill *A* half full of water; place both under the receiver of an air pump and exhaust the air. At the first stroke the water from *A* will begin to run into *B*. Explain.

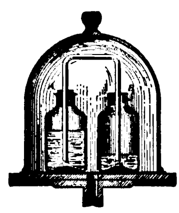


FIG. 151

Exhaust until nearly all the water is drawn over, and then let air into the receiver. The water will run back into A. Explain.

168. The Buoyant Force of the Atmosphere. — A body submerged in water is buoyed upward by a vertical upward force that is equal to the weight of the displaced water. This pressure amounts to 62.5 lb. for each cubic foot of the volume of the submerged body. Since the air has weight, a body is buoyed up by it in the same way. The amount of the lifting force is as much less than that produced by water as the air is lighter than water. Air at sea level weighs $\frac{1}{773}$ of the weight of water, or about 0.08 lb. per cubic foot. This means that the lifting power of the air on a spherical balloon 20 ft. in diameter is over 338 lb. at the surface of the earth. As the rarity of the air increases with the distance from the earth, the lifting power is less at high altitudes.

169. The Airplane. — The aëroplane or airplane is a heavier-than-air machine which is lifted by the thrust of the air upon the under sides of its planes when they are driven through it at high speed. This speed is secured by the push of a light screw propeller that rotates very rapidly, being driven by a special form of gasoline engine.

The four main parts of an airplane are: (1) the principal planes, wings, or glider unit; (2) the body unit; (3) the tail unit; (4) the undercarriage or chassis.

Airplanes are monoplanes, biplanes, or triplanes, dependent upon the number of principal planes. The ailerons, or wing flaps, are usually placed at each wing tip and are used to stabilize the airplane and to bank or tip it out of the horizontal position in turning.

The body of the airplane contains the engine, fuel, pilot, passengers, and load. If the airplane is of the tractor type,

FIG. 152. — The American Seaplane NC 4 in Flight; the first Airplane that flew across the Atlantic Ocean (1919)

FIG. 153. — A Close-up View of the NC 4, Showing the Wings and Body

having its propeller in front, the body is extended backward to support the tail planes and is called the *fuselage*.

The tail unit consists of both horizontal and vertical planes. These are movable and are under the control of the pilot. They serve both to stabilize the airplane and to control the direction of its flight. A change in the position of the horizontal tail plane changes the altitude of the airplane by pointing its nose upward or downward, while a change in the position of the vertical tail plane changes its line of flight either to the right or to the left.

The undercarriage, or *chassis*, usually consists of one or more pairs of wheels in front and a skid in the rear. These are used for running over the surface of the ground at the beginning of a flight until enough speed is attained to enable the plane to rise into the air; they are also used in landing at the end of a flight.

Fig. 154. — Airplane Instruments

A, ignition switch; *B*, light switches; *C*, pressure pumps; *D*, revolution counter showing the number of revolutions of the propeller; *E*, map; *FG*, control wheel; *H*, altimeter indicating height; *I*, oil pressure gauge; *J*, barometer; *K*, compass; *L*, air speed indicator; *M*, gas throttle.

In seaplanes (Fig. 152) the wheels and skids are replaced by floats that help to support the body of the plane above the surface of the water. Figure 154 shows a number of the most useful instruments used by the pilot of an airplane.

170. Measurement of Atmospheric Pressure. — While the above experiments have demonstrated the existence of atmospheric pressure, they have given no accurate idea of its amount. The principle employed in finding its amount is the same as that of balancing columns used in finding the specific gravity of liquids. If a bottle is filled with water and inverted with its mouth under the surface, as in Fig. 155, the water will remain in the bottle. The downward pressure of water in the bottle *A* is counterbalanced by the downward pressure of the air upon the surface of the water in *B*, since the downward pressure upon the surface is transmitted into an upward pressure at the mouth of the bottle.

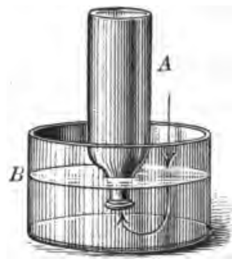


Fig. 155

In order to balance the entire pressure of the atmosphere by a water column, the bottle in Fig. 155 would need to be extended into a tube about 34 ft. long; but by using a liquid heavier than water, a correspondingly shorter tube can be used.

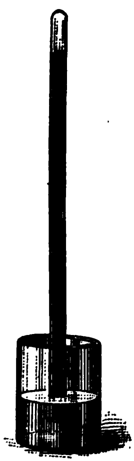


Fig. 156

Demonstration. — Close one end of a glass tube 80 cm. long and about 6 mm. in internal diameter. Fill it nearly full with clean mercury. Close the open end with the finger, and invert it several times to remove all air bubbles clinging to the sides of the

tube. Now fill the tube full, put a finger over the open end, invert it, and place the open end beneath the surface of mercury in a dish. Remove the finger carefully so that no air shall get into the tube. The mercury will fall a little, and the height at which it stands will measure the atmospheric pressure (Fig. 156).

171. Atmospheric Pressure at Sea Level. — The average height at which the mercury column stands, at the level of the sea, is 76 cm., and this height is independent of the diameter of the tube. If the area of the cross section of the tube is 1 sq. cm., the volume of the mercury will be 76 c.c., and since its specific gravity is 13.596, its weight will be 1033.3 g. In English measure the average height of the column is 30 in., and if its cross section is 1 sq. in., its weight will be 14.7 lb. Since this weight is the measure of the pressure of the air, we can state the following:

The average pressure of the atmosphere at sea level is 14.7 *lb. per square inch, or* 1033.3 *g. per square centimeter.* This is called a pressure of **1 atmosphere,** and as it is constantly changing, it is often called in round numbers 15 lb. per square inch, or 1 kg. per square centimeter.

172. The Barometer. — The experiment with the glass tube filled with mercury was first made by Torricelli in 1643, and the space above the mercury column in the tube is called a *Torricellian vacuum.*

The mercurial barometer consists of a glass tube about 34 *in. long, filled with mercury, and inverted with its lower end constantly below the surface of mercury in a cistern.* It is fixed in a vertical position with a scale C graduated along the top near the end of the mercury column, the zero of this scale being the surface B of the mercury in the cistern A at the bottom (Fig. 157).

In reading the barometer a vernier scale is generally used to secure accuracy. The vernier must be brought to the top of the convex surface of the mercury, and the eye must be on a horizontal line from the top of the column; this may be secured by placing a small vertical mirror behind the top of the column, and placing the eye so that its image and the top of the column coincide. Before the height is read, the surface of the mercury in the cistern must be brought to the fixed zero. This is done by turning the screw *c* which raises or lowers the mercury in the cistern until it just touches the point of a pin projecting downward from the frame of the instrument, which point is the zero of the scale.

If a liquid less dense than mercury is used, the column will be correspondingly longer, and changes in it, caused by changes in atmospheric pressure, will be correspondingly greater. The glycerin barometer has a height of about 27 ft., and a change of nearly 11 in. for every change of 1 in. in the mercury barometer.

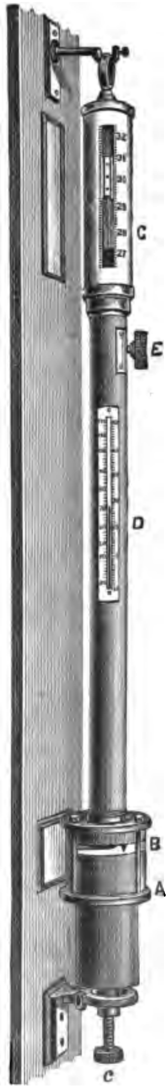


Fig. 157

173. The Aneroid Barometer takes its name from two Greek words meaning "without fluid." It consists of a circular box of thin metal, with corrugated sides, a cross section of which is shown in Fig. 158. One side of the box, or vacuum chamber, as it is called,

is firmly fixed to the base of the instrument. The air is partly removed from the box and it is sealed air-tight.

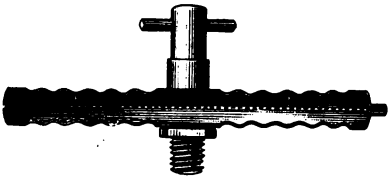


FIG. 158

Variations in the atmospheric pressure cause corresponding changes in the position of the elastic upper face of the vacuum chamber, and these changes are transmitted by a system of delicate levers to a pointer which moves around a graduated dial. The readings of this dial are made to correspond to those of a standard mercury barometer.

FIG. 159.—Aneroid Barometer

These instruments are very delicate and will show a variation in reading on being raised from the floor to a table; for *the atmospheric pressure varies not only with the weather but also with the elevation above sea level.* If an aneroid barometer is carried in an elevator from the street floor to the top floor of a high building, the decrease of air pressure from floor to floor is readily seen. It is on account of this decrease in atmospheric pressure that the pressure of illuminating gas is apparently greater at the top of a building than at the base. The pressure forcing the gas from the tube is the difference between the pressure in the pipes and the pressure of the air. Since the air pressure is greatest at the base of the building, the excess pressure of the gas is greater at the top.

The *barograph* (Fig. 160) is an aneroid barometer with attachments that make a permanent record of its readings.

174. Weather Indicated by the Barometer. — A constant use of the barometer is made in the Weather Bureau in fore-

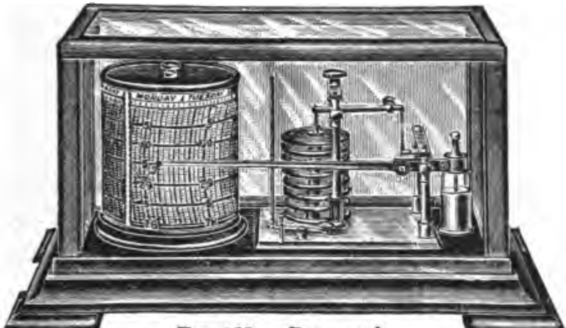


FIG. 160. — Barograph

casting changes in the weather. The relation of barometric readings to the state of the weather may be stated as follows:

I. *A rising barometer precedes fair weather.*

II. *A falling barometer precedes foul weather.*

III. *A sudden fall in the barometer precedes a storm.*

IV. *An unchanging high barometer indicates settled fair weather.*

175. Cyclonic Storm Pressure. — The relation between the readings of the barometer and the direction of the wind in circular or cyclonic storms may be studied in connection with the weather map, Fig. 161. At the center, or eye of the storm (marked LOW), the pressure is least; while at the outside the pressure is greater, and the air therefore rushes toward the center. In

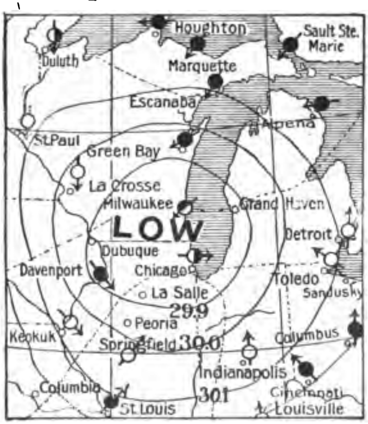


FIG. 161

the northern hemisphere winds are deflected to the right by the rotation of the earth. In approaching the center of low pressure, therefore, the direction of each air current is to the right of the center. This gives to the storm a rotary motion in a counter-clockwise direction; and if a person stands with his back to the wind, the storm center, or region of lowest barometer, will be on his left hand.

The observations of the Weather Bureau on barometric pressures for a series of years indicate that there is a well-defined movement of low pressures, or storm centers, across the continent. These areas of low pressure generally enter the United States on the northwest boundary, coming from British America, move southeastwardly until they have crossed the Rocky Mountains, and then turn northeastwardly and disappear on the Atlantic coast, or pass down the St. Lawrence River. The storms that come into the country from the Gulf of Mexico usually travel northeast along the Altantic coast.

176. Height of the Atmosphere. — The compressibility of the air is so great that the layer in contact with the surface of the earth is more dense than the layers above it. Though the density constantly decreases as the distance from the earth increases, no uniform rule can be given that will show the relation between barometric readings and the corresponding heights of the atmosphere. However, a fall of one inch in the mercury column, from the reading at sea level, indicates an elevation of about 900 ft.

Figure 162 is a graph showing the relation (in fair weather) between height above the surface of the earth in feet and the pressure of the atmosphere as measured by inches of mercury. It is seen from this curve that at a height of 20,000 ft. the pressure is reduced from 31 in. of mercury to

less than 15, which means that the density of the air is not half so great at that height as at the surface.

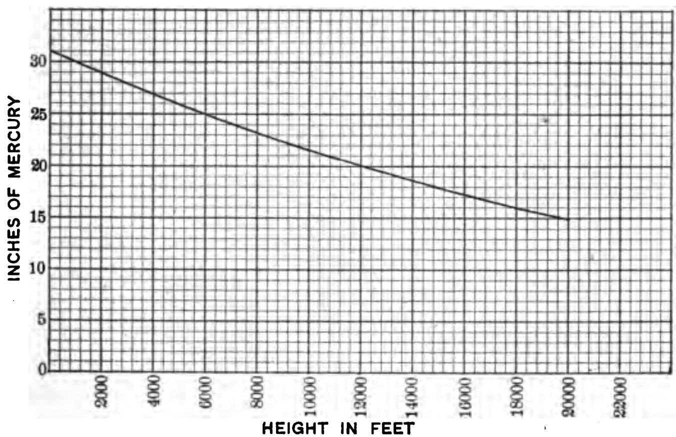


FIG. 162. — Atmospheric Pressure at Different Heights

Balloon ascensions have exceeded this height, notably that of Mr. James Glaisher, undertaken for the purpose of making scientific observations for the British Association for the Advancement of Science. Both Mr. Glaisher and his aëronaut, Mr. Coxwell, became unconscious, but before losing consciousness succeeded in letting enough gas escape to bring the balloon down into the denser atmosphere. The pressure recorded by the instruments indicated a height of 37,000 ft. The height of 36,020 ft. was reached on February 27, 1920, by Major R. W. Schroeder, who drove an airplane from McCook field, Dayton, Ohio. The extreme cold at this height rendered him temporarily blind. His machine fell five miles but was righted at 2000 feet and made a safe landing.

177. Boyle's Law. — Since an increase of pressure reduces the volume of a gas, it is important to know whether there is a definite relation between the pressure exerted upon a gas and the resulting volume. This was experimentally deter-

mined independently by two physicists, Boyle and Mariotte. The results obtained were formulated in what is called *Boyle's Law*, which may be stated as follows:

The temperature remaining the same, the volume of a given mass of gas varies inversely as the pressure acting upon it. This may be expressed by the proportion $V : V' = P' : P$, from which we get

$$PV = P'V', \tag{40}$$

$$i.e., \ PV = \text{a constant quantity.}$$

The mass of the air remaining the same, it is evident that the density must increase as the volume diminishes; hence,

At a constant temperature the density of a gas is directly proportional to the pressure acting upon it.

Very careful measurements show that gases do not obey Boyle's Law exactly, and that different gases behave differently in this respect. But for practical purposes the law may be considered to hold true, except at temperatures so low that the gas is about to liquefy.

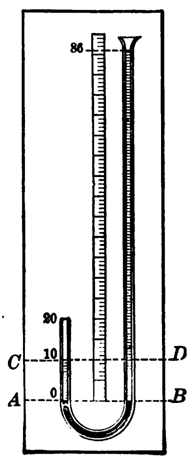


FIG. 163

178. Verification of Boyle's Law.—(*a*) *For Pressures Greater than One Atmosphere.* — **Demonstration.** — Bend a glass tube as shown in Fig. 163, the long arm being open and the short one closed. Fix this to a vertical support and place a graduated scale between the two arms. Pour mercury into the long arm by means of a long funnel, and tip the tube in such a way as to let bubbles of air pass from the short tube into the long one, and thus bring the mercury to the same level AB in both. This line is chosen at a convenient position, say 20 cm. below the closed end. On pouring mercury into the long tube it will be found necessary to fill it to a height of about 760 mm. above the mercury in the short tube to reduce the volume of the gas one half. The pressure upon

the mercury in the short tube is the elastic force of the air above it, and this is equal to the pressure above the line CD in the long tube, which is two atmospheres, one being the 760 mm. of mercury and the other the free atmosphere above it. State how this proves the law.

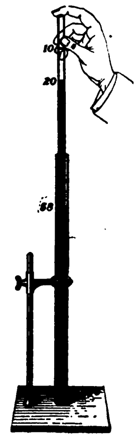


FIG. 164

(*b*) *For Pressures Less than One Atmosphere.*— **Demonstration.** — Fix vertically a glass tube closed at the lower end, about 70 cm. long and at least 8 mm. in internal diameter. Cut off a piece of glass tubing 6 or 7 mm. in external diameter and make three marks upon it, one at 10 cm., one at 20 cm., and one at 58 cm. from one end. Pour mercury into the large tube until, on thrusting the smaller tube into it with the 10 cm. mark uppermost, the mercury will rise to the 10 cm. mark. Place the finger over the top and inclose a column of air 10 cm. long. This has an elastic pressure of 1 atmosphere and just balances the pressure on the surface of the mercury in the larger tube. Now raise the smaller tube until the mercury sinks to the 20 cm. mark on the inside of the tube; what is now the elastic pressure of the inclosed air? On the outside the mercury will stand nearly at the 58 cm. mark. Why?

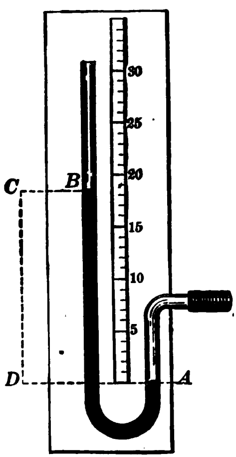


FIG. 165

179. The Manometer is an instrument for measuring the pressure of gases. It is made in two forms, the open and the closed.

(*a*) *The Open Manometer* consists of a bent glass tube held in a vertical position by a frame having a graduated scale between the two arms of the tube (Fig. 165). Mercury or some other suitable liquid is poured into the manometer so that it stands at the

same height in both arms. The short arm is connected with the vessel containing the gas, and when the gas is turned on, the pressure is shown by the difference in level of the columns. The length of the column of liquid CD is the measure of the pressure in excess of 1 atmosphere.

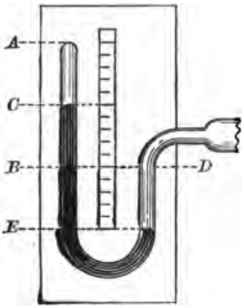


Fig. 166

(*b*) *The Closed Manometer* (Fig. 166), or *pressure gauge,* differs from the open manometer in being closed at one end and much shorter. Before the pressure is turned on, the mercury stands at the level BD, with the ordinary atmospheric pressure in each arm. When the stopcock is turned, the pressure of the gas not only maintains the pressure of the mercury column CE, but also compresses the volume of air from AB to AC. Pressure gauges are calibrated to show the pressure in excess of 1 atmosphere.

In a closed manometer sometimes used to measure small pressures, the closed end of the tube is entirely filled with mercury at atmospheric pressure. As the air is exhausted from the vessel with which the manometer is connected, the mercury sinks in the closed end; the height of the column shows the pressure just as a barometer does.

180. The Siphon is a bent tube with arms of unequal length, used to transfer a liquid from one vessel to another at a lower level by carrying the liquid over the edge of the vessel. A flexible rubber tube makes a very convenient siphon.

Demonstration. — Fill a siphon tube like that shown in Fig. 167 with water and close the end of the long arm with the finger. Invert it and place the end of the short arm below the surface of water in a

beaker. The water will begin to flow at once, and will continue to flow until the water in the beaker is below the end of the tube.

181. Cause of the Action of the Siphon. — At the level of the water surface *A* (Fig. 167), the upward pressure in the short arm of the siphon is the atmospheric pressure, while the downward pressure is the weight of the water column *AB*. The upward pressure at the point *D* is also the atmospheric pressure, and the downward pressure is the weight of the water column *DC*. The resulting upward pressure at any point will be the atmospheric pressure minus the pressure of the water column at that point, and as the column *CD* is longer than the column *AB*, the resulting upward pressure at *A* is greater than at *D*, and the water is forced from *A* toward *D*.

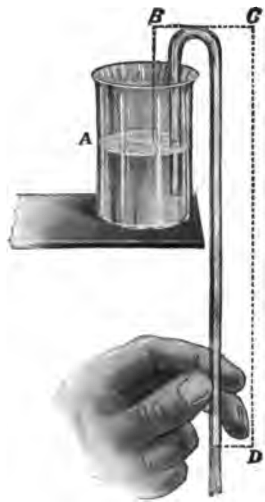


FIG. 167. — Siphon

It is evident that unless the pressure due to the liquid column *AB* is less than the pressure of the atmosphere, there will be no flow of the liquid. Hence a siphon cannot raise water more than 34 ft., nor mercury more than 30 in., when the barometer stands at the normal height.

The final resultant of the pressures depends upon the difference in the heights of the liquid columns; hence the greater the difference in height, the faster will be the flow.

It is evident that the size of the tube used as a siphon does not affect the height to which a liquid can be raised, since both the downward pressure of the liquid column due to its weight and the total upward pressure of the atmos-

phere at the end of the tube are directly proportional to its area of cross section.

182. The Lifting Pump. — There is practically no difference between the suction or lifting pump and the simple air pump. In both the valves open upward and should be air-tight. From the base of the cylinder of a lifting pump a tube runs to the water supply, and near the top of the cylinder is a spout for carrying off the water. When the pump is started, the air is first pumped out. On the up stroke of the piston, pressure is removed from the top of the lower valve and atmospheric pressure causes water to rise in the tube *T*, finally filling the space below the piston. On the down stroke of the piston the lower valve closes, holding the water above it. Water is forced through the piston valve. On the next up stroke of the piston, water is lifted out (Fig. 169). It will be seen that the upper valve must be placed so that its highest position shall not be more than 34 ft. above the level of the water in the cistern. About 27 ft. is the practical limit.

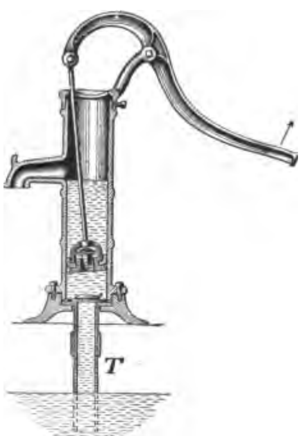


Fig. 168. — Down Stroke of Piston

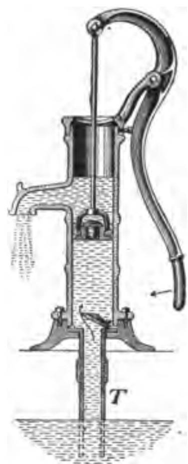


Fig. 169. — Up Stroke of Piston

183. The Force Pump, like the condenser, applies pressure to the stream sent from the pump. The force pump shown in Fig. 170 differs from the ordinary lifting pump in having the upper end of the cylinder closed water-tight, and in the addition of the valve *V* and air chamber *A*. The elasticity of the air cushion in *A* forces the water out at *P* in a steady stream, though it comes in through *V* only during the upward stroke of the piston.

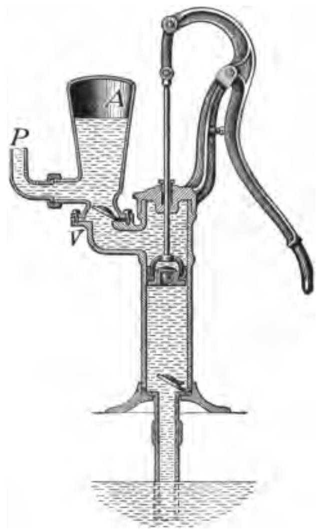


Fig. 170. — Force Pump

184. Centrifugal and Rotary Pumps. — In centrifugal and rotary pumps, the moving parts have a circular motion only, instead of the reciprocating motion of the piston in the lifting and force pumps. A centrifugal pump is a reversed turbine. Any reaction turbine, if run backward by power applied to its axle, will force water up the penstock. The supply pipe for a centrifugal pump delivers the water at the middle of the wheel, and the discharge pipe opens from the circumference of the case.

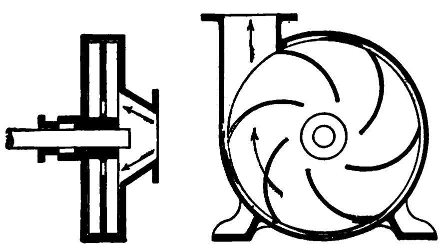


Fig. 171

In the rotary pump there are two wheels with interlocking

spurs that rotate in opposite directions. Centrifugal pumps are used to furnish a circulation of cold water for steam condensers. Figure 172 shows a motor-driven circulating

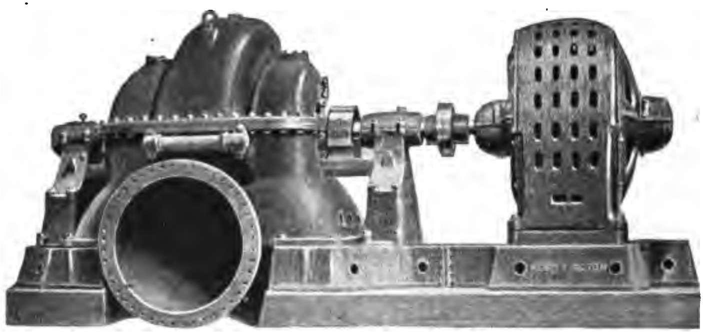


FIG. 172.—A 48-Inch Circulation Pump, 60,000 G. P. M., 20-Foot Head

pump with a capacity of 60,000 gallons per minute through its 48-inch discharge pipe. Various forms of centrifugal pumps are used in vacuum cleaners.

185. Absorption of Gases by Solids. — Some porous solids have the property of absorbing gases to a great extent, a given body of the solid absorbing many times its own volume of the gas.

FIG. 173

Demonstration. — Trim a piece of charcoal about an inch long so that it will slip easily into a large test tube. Invert the tube and fill it with ammonia gas. Pour mercury into a dish and place the piece of charcoal on its surface. Bring the test tube down over the charcoal and fix it in such a position that its mouth will be a little below the surface of the mercury. In a short time, the charcoal will absorb the ammonia, and the mercury will rise in the tube, as in Fig. 173.

A most important application of the gas-absorbing property of charcoal has been made in the construction of gas masks to absorb poisonous gases. The degree to which the absorption is carried depends largely upon the character of the charcoal used. This is determined not only by the material from which the charcoal is made, but also by the process of manufacture. Charcoal made from coconut shell and peach stones is of high absorptive quality and is capable of being broken into small pieces, thus increasing its surface, without crumbling into dust.

The charcoal, with soda, lime, and cement granules, is placed in an absorbing chamber or canister and moistened with a suitable chemical solution, sodium hyposulphite, for example, for the absorption of chlorine.

Fig. 174. — Gas Mask

While primarily made for the protection of soldiers in war, the gas mask has many uses in times of peace, such as protection against noxious gases in coal mines.

The mask shown in Fig. 174 is for protection against ammonia fumes. The air inhaled passes first through a canister containing the prepared charcoal. The exhaled air is released through a flutter valve in front of the neck.

186. Absorption of Gases by Liquids. — Liquids also absorb gases more or less freely. The bubbles of air rising from a glass of water when it is placed under the receiver of an air pump and the air is exhausted, afford evidence that air is absorbed by water. It is on account of the absorbed air that fish are able to live in water. Water at normal pressure and temperature absorbs nearly twice its volume of carbon dioxide and more than a thousand times its volume of ammonia gas.

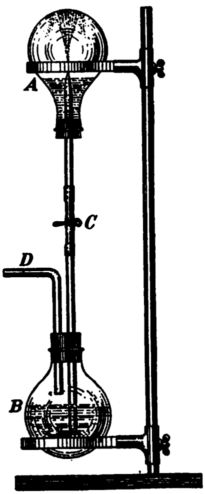


FIG. 175

Demonstration. — Fit two flasks with rubber stoppers, one having two holes and the other one (Fig. 175). Draw out a glass tube to a jet and thrust it into the upper flask A after having filled A with ammonia gas. Thrust two tubes of the forms shown in the figure through the other stopper. Fill the lower flask B nearly full with a solution of litmus reddened with a few drops of acid. Press in the stopper and connect the two straight tubes with a short piece of rubber tubing having a clamp at C. Loosen C and force a little water into A by blowing through the pipe D, and the water will continue to flow until the flask A is nearly full. The quantity of water that goes into A will measure roughly the gas absorbed. Notice the change in the color of the water in A. What proof is there that there was not a vacuum in the upper flask?

The escape of bubbles from water under the receiver of an air pump not only proves the existence of the absorbed air, but also proves that the amount absorbed depends upon the pressure. This fact is made use of in charging a soda fountain. This is done by letting a quantity of carbon dioxide flow from a high-pressure tank into a cylinder partly filled

with water, and rocking the cylinder vigorously until the gas is absorbed. The large amount of gas absorbed under pressure is shown by the effervescence of the water when it is drawn out into a glass.

187. Diffusion of Gases. — If a closed vessel containing a gas is connected with another containing any different gas, no matter what its density, the gases will diffuse completely.

Demonstration. — Fit a large rubber stopper with one hole into the open end of a porous cup, such as is used in small battery jars. Put one end of a glass tube about 2 ft. long through the stopper, and hold the tube inverted with the open end below the surface of water in a dish. Bring over the porous cup a jar filled with hydrogen, or with common illuminating gas, and bubbles will be seen to rush from the end of the tube and rise through the water, showing that gas has passed into the cup. After the bubbles stop rising, remove the jar and notice what follows.

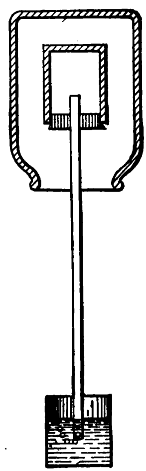


FIG. 176

It has been proved that a given volume of a gas contains the same number of molecules as the same volume of any other gas at the same pressure and temperature, and hence that the molecules of a light gas have a greater velocity than those of a heavy gas. Since the velocity of the molecules of the gas in the outer jar is much higher than that of the air molecules in the inner cup, the number that strike the outside of the porous cup is correspondingly greater than the number that strike the inside. This means that a greater number will pass through the pores of the cup from the outside to the inside than in the opposite direction, hence the excess has to pass

out of the lower end of the tube. As the number of gas molecules increases within the cup, the number of impacts on the inside finally becomes equal to the number on the outside, and no further bubbles will escape. When the outer jar is removed, the conditions and results are reversed.

Questions

1. How does a gas differ from a liquid?

2. How does the elasticity of a gas differ from the elasticity of a spring?

3. Why is it possible to pump air from a closed vessel?

4. When will an air pump stop taking air from a receiver? Is it possible to take it all out?

5. What will take place if the tip of an incandescent lamp bulb is broken off under water? Why?

6. Why does an arrow with a cup-shaped rubber tip, stick to the wall when shot against it?

7. To what volume must a cubic foot of any gas be compressed to make its elastic force three times as great?

Fig. 177

8. Why do we not feel the pressure of the atmosphere?

9. What advantage is there in having a pneumatic tire on an automobile?

10. Why does a deep sea fish look bloated when brought to the surface?

11. Suppose a piece of rubber hose is used to siphon water from the barrel into the pail (Fig. 177). Will the water run faster when the barrel is full or when nearly empty?

12. Suppose a hose is used to siphon water from a pit in the side of a hill, how far below the opening of the pit will it draw the water?

Problems

(The normal air pressure, when not otherwise given, is to be reckoned as 14.7 lb. per square inch or 1033.3 g. per square centimeter.)

1. A rubber balloon is placed under the receiver of an air pump. The pump is worked until the volume of the air in the balloon changes from 128 c.c. to 352 c.c. What is the pressure in grams per square centimeter?

2. Suppose the air to be all removed from an air-tight cubical box 2 ft. on each edge. What would be the pressure of the atmosphere tending to crush the box?

3. A tank contains 3.2 cu. ft. of hydrogen gas under a pressure of 275 lb. per square inch. If the gas were allowed to expand until the pressure was 16 lb. per square inch, how many cubic feet would it occupy?

4. To what volume must a cubic foot of gas be reduced to make its elastic force five times as great?

5. How deep must water be in a box so that its pressure upon the bottom may be the same as that of the atmosphere?

6. If the box in problem 5 were 6 ft. square, how much would the air in it weigh?

7. A tank under a street car has a capacity of 4 cu. ft. and is filled with air under an atmospheric pressure of 15 lb. per sq. in. How many additional cubic feet of air must be forced into the tank to raise the pressure to 90 lb. per square inch?

8. How many times the volume of air in an automobile tire at an atmospheric pressure of 15 lb. per square inch must be forced into it to have the pressure gauge read 80 lb.?

9. How much excess of pressure is there per square foot on the inside of a steam boiler over that on the outside when the pressure gauge (§ 179, *b*) reads 73.5 lb.?

10. How many foot pounds of work are done by a compressed air engine during each stroke, if its piston is 16 in. in diameter, and the stroke is 18 in., when the gauge shows an air pressure of 4 atmospheres?

11. To what height would the atmospheric pressure sustain a water column if the barometer reading is 29.8 in.?

12. The specific gravity of glycerin being 1.26, what will be the

reading of a glycerin barometer when the mercury barometer reads 753 mm.? What change in the height of the glycerin column will correspond to a change of 1 mm. in the mercury column?

13. The altitude meter of an airplane reads 12,000 ft. What should the barometer read at that height according to Fig. 162?

14. Pikes Peak is 14,108 ft. high. According to the graph in Fig. 162, what is the height of the barometer at the summit during fair weather? How does the density of the air there compare with that at the level of the sea?

15. A closed manometer like that in Fig. 166 is attached to a tank of compressed air. The air in the manometer is reduced to one fourth its original volume, and the difference of level in the mercury columns is 30 cm. What is the pressure in the tank in excess of one atmosphere?

16. The difference in the height of the two water columns in an open manometer is found to be 14 cm. when the manometer is attached to a gas jet. By what part of an atmosphere does the pressure of the gas exceed that of the air?

17. Over what height can water be carried by a siphon when the barometer reads 29.1 in.? What effect will it have upon the flow to reduce this height to 10 ft.?

18. When the pressure on the interior of an incandescent lamp sustains a column of mercury only $\frac{1}{2}$ mm. high, what is the pressure in grams per square centimeter?

19. A diver is working in 30 ft. of sea water, the sp. gr. of which is 1.025. What pressure must be supplied by the compression pump to counterbalance the water pressure?

20. A force pump drives water to a height of 156 ft. What pressure in pounds per square inch of surface must be supplied by the piston?

21. A balloon contains 500 cubic meters of hydrogen which weighs 90 g. per cubic meter, and displaces 505 cubic meters of air. The balloon covering and car weigh 300 kg. Each cubic meter of the surrounding air weighs 1290 g. How many kilograms will the balloon lift in addition to its own weight?

CHAPTER VI

SOUND

I. WAVE MOTION AND VELOCITY

188. Simple Harmonic Motion. — If a heavy ball, suspended like a pendulum, is given a circular motion in a horizontal plane, the cord by which it is suspended will describe the surface of a cone, and the arrangement is called a conical pendulum. To an eye at E, in the same horizontal plane as that in which the ball is moving, the ball seems to be moving in a horizontal straight line, projected on the wall at AB.

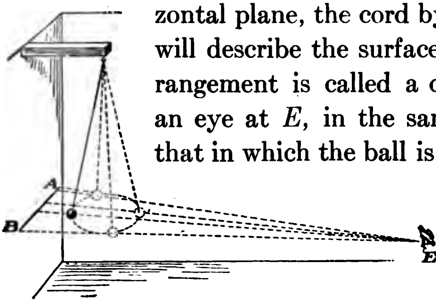


FIG. 178

Though the ball is moving with uniform velocity around its circular path, the projected motion is a to-and-fro motion, like that of an ordinary pendulum. The velocity of this projected motion is greatest at the middle of the path AB and decreases to zero at A or B.

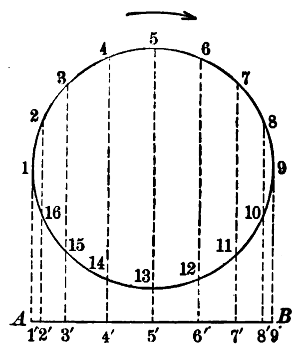


FIG. 179

If the path of the ball is represented by the circle in Fig. 179, the corresponding position on the line AB, at any time, can be found as follows, if we assume that E is at

a distance so great that the lines EA and EB are practically parallel: divide the circle into any convenient number of parts, 16, for example. From the dividing points 1, 2, 3, etc., drop perpendiculars to the line AB, meeting it at the corresponding points $1'$, $2'$, $3'$, etc. Any body moving to and fro along the line AB in such a way that its position at any time corresponds to the projection on AB of a body moving with uniform velocity around the circle of reference, is said to have a *simple harmonic motion*. It is evident that the distances $1'$–$2'$, $2'$–$3'$, etc., are passed over in equal times.

189. Vibrations and Wave Motion. — A body or a particle that has simple harmonic motion is *vibrating*. The greatest distance reached from the position of rest is the *amplitude* of the vibration. The vibration is *longitudinal* when this motion has the same direction as the length of the vibrating body; it is *transverse* when the motion is perpendicular to the length.

When rapid vibrations are set up in one part of an elastic body, they are transmitted to the other parts in the form of *waves*.

Demonstration. — Procure a half-inch spiral coil of spring brass wire 10 or 12 ft. long, or make one by winding the wire on a piece of

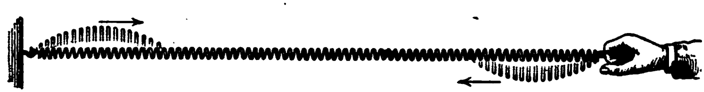


Fig. 180

gas pipe fixed to turn in a lathe. Hook one end of the coil to a screw hook in a post, and taking the other end in the hand, stretch it somewhat. Strike the coil a light, vertical blow near the hand, and a wave will run to the fixed end and return (Fig. 180). The sudden jerk felt by the hand as the reflected wave strikes it shows that the wave transmits the energy of the blow.

190. Wave Length. — One particle of a body transmitting waves is in the same *phase* as another particle when it is moving in the same direction with the same velocity at the same time. Figure 181 shows the form of a wave, due to transverse vibrations, moving from left to right. The particle *A* is moving downward with a certain velocity, and the next particle that is in the same phase is *E*. The particle *C* has the same velocity, but is moving upward. The distance between any particle and the next particle in the same phase, measured in the direction of wave motion, as *AE*, is the *wave length*. The top of the wave at *B* is called the *crest*, while the bottom at *D* is the *trough*. The vertical distance from *B* to the horizontal line (that is, half the vertical distance between *B* and *D*) is the *amplitude*. It is a simple matter to make a body record its own vibrations by tracing a wave form similar to Fig. 181.

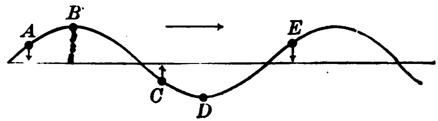


FIG. 181

Demonstration. — Bore a hole near the end of a long piece of whalebone, and fasten it by a screw to the side of a block screwed to a board. Rub a few drops of kerosene or cosmolene on one side of a strip of glass so that the surface is evenly covered with a thin layer. Put some flour in a muslin bag and dust it evenly over the glass. Place on the board between two guides and underneath the whalebone. Fix a bristle to the whalebone near the end so that it will just touch the glass. Vibrate the whalebone, and the bristle will make in the flour surface a nearly straight line twice the length

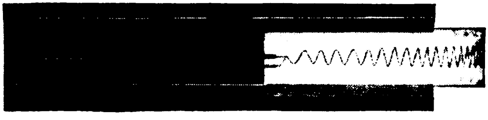


FIG. 182

of the amplitude. Vibrate the whalebone again, and raise one end of the board so that the glass will slide out, and the vibrations will trace a beautiful wave form, as shown in Fig. 182. Since the motion of the glass strip is changing, the wave form is variable. If the strip is drawn out with uniform velocity, the wave form will closely approximate that shown in Fig. 181.

191. Water Waves of small amplitude are, as a whole, similar to those produced by transverse vibrations in a stretched cord. The particles of the water, however, move in small circles or ellipses, while the wave moves onward. This can be observed by watching the motion of a boat at a distance from the shore; the boat rises and falls with the waves, but does not advance with them. Near the shore the velocity of the wave below the surface is retarded by the sloping bottom and the outgoing water, so that the top of the wave curls over, forming a breaker, which moves in the direction of the wave.

192. Sound Defined. — The physical definition of sound is any vibration that is capable of being perceived by the ear. The physiological definition includes also the effect produced upon the ear by such vibrations.

193. A Sounding Body is a Vibrating Body.— Demonstrations. — Hold a large jar, like the receiver of an air pump, horizontally by the knob, and draw a bow across the edge, or strike it lightly with a cork hammer. Is it a sounding body? Place a few carpet tacks inside the jar near the edge. Repeat the experiment. Is the jar in vibration?

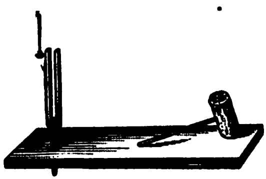


Fig. 183

Bore a hole in the top of a table and firmly set into it the handle of a tuning fork. Make a cork hammer by thrusting one end of a knitting needle through a large cork. Tie a shoe button to the end of a fine silk thread. Strike one prong of the fork with the hammer, and hold the button

on the side of the fork near the top. Do its movements prove that the fork is a vibrating body? Why does not the button rebound to the same distance every time? Gradually lower it along the side. What is the effect? Hold the button between the prongs and observe.

Both these experiments prove that *a sounding body is in vibration.* An interesting way to show the vibration of a tuning fork is to set it in motion, and then bring it in contact with the surface of water upon which lycopodium powder has been scattered. The rapid blows of the prong will give rise to a beautiful set of waves.

194. The Transmission of Sound. — The vibrations of a sounding body may be transmitted by any elastic substance. Gases, liquids, and most solids transmit sound, but with varying intensities and velocities.

(*a*) *Gases.* — That gases transmit sound is a matter of universal experience, since the air is the common medium of sound transmission.

(*b*) *Liquids.* — Sound is transmitted by liquids more readily than by gases. A person swimming under water can hear with great distinctness the sound of two stones struck together under the surface.

(*c*) *Solids.* — A long wooden rod, a section of gas pipe, or the wires of a wire fence can be used as a means of proving that elastic solids are good conductors of sound. If an observer places his ear at one end of any of these, while the other end is scratched with a pin, the sound of the scratching is plainly heard through the solid body, though it may be entirely inaudible through the air.

195. Sound not Transmitted in a Vacuum. — **Demonstration.** — Fit a rubber stopper to an air pump receiver with a small neck. Beside this run two No. 30 insulated copper wires attached

to an electric bell. Thrust the stopper in firmly to make the receiver air-tight. Exhaust the air so far as possible, and ring the bell by connecting the wires with a battery. Notice that the sound of the bell is very faint. Slowly admit the air, and notice how the sound increases in intensity. A perfect vacuum transmits no sound.

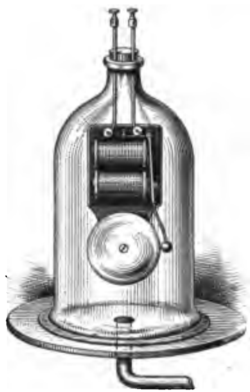


FIG. 184

196. Wave Motion in Air.—Sound is transmitted by means of waves, but the particles of air do not vibrate transversely as in the coil in § 189; they vibrate longitudinally—that is, in the same direction as that in which the waves are moving. The molecules that are put in motion by the first forward movement of a sounding body are suddenly pushed ahead of it and crowded nearer together, forming a *condensation;* but their path is not long, since they strike other molecules, which in turn set the molecules next to them in motion. When the sounding body moves back, it leaves a partial vacuum, or *rarefaction,* behind it, and into this the molecules we have

FIG. 185.—Section through Sound Waves

been considering rush back. This sets up the to-and-fro motion of the air that constitutes a sound wave. The condensations and rarefactions move rapidly outward in all directions from the sounding body, and follow in regular succession as long as the sounding body continues to vibrate, at intervals that depend upon the rate of the vibration. In Fig. 185 the dark rings represent condensations and the light rings rarefactions in a train of sound waves proceeding from a sounding body at the center.

Demonstrations. — Hook one end of the wire spring as before (§ 189), and stretch the spring somewhat by pulling on the other end. Put a knife blade between two of the turns of wire and draw it toward the end held by the hand, pushing a few of the coils together. Remove the knife suddenly, and the wave will run the length of the spring and be reflected by the hook back to the hand. Tie a piece of thread to the spring at the middle, and the longitudinal vibrations will be shown by the sudden, jerking, to-and-fro motion of the thread.

That a mechanical impulse can be sent through the air as a wave form can be shown by the use of a tube 8 or 10 ft. long and 3 in.

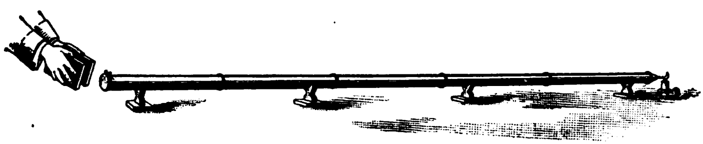


FIG. 186

in diameter. One end of this tube is capped with a cone having an opening an inch in diameter at the small end, while the other end is covered by a sheet of thin rubber tightly stretched and tied in place. A short piece of candle is lighted and so placed that the flame comes opposite the end of the cone. When two wooden blocks are struck sharply together near the closed end, the flame suddenly flares away from the end of the tube. The same thing occurs when the rubber diaphragm is tapped lightly with the finger. There is no passage of air through the tube, for the end is closed; hence the

movement of the candle flame is the result of the blow received from the condensed wave sent out by the movement of the diaphragm.

197. Graphical Representation of a Sound Wave. — In a sound wave the motion of each particle of air is either a simple harmonic motion or a combination of two or more such motions. Though the vibration is longitudinal, the wave may be represented by a curve similar to that in Fig. 181 if we understand that all the particles really move to and fro in the direction of the horizontal line, and that the distances

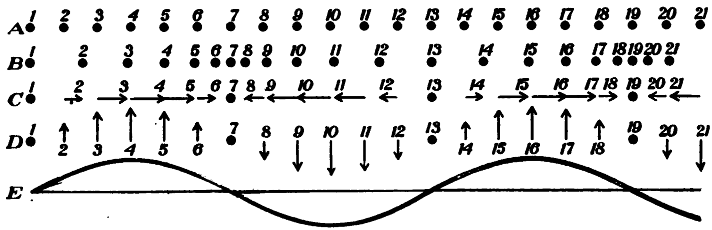


Fig. 187

A, particles at rest, when there is no sound; *B*, same particles at one instant in a train of sound waves; *C*, extent of displacement from position of rest (*not* direction of present motion); *D*, same displacements represented by vertical lines; *E*, the curve

A, *B*, etc., above this line *represent* displacements to the right, and *C*, *D*, etc., below the line, displacements to the left. Figure 187 illustrates how such a curve can be drawn.

198. The Velocity of Sound in Air has been found directly by taking the interval between the time when the flash of a gun is seen, and the instant when the report is heard. The distance between the two stations, divided by the time in seconds, gives the velocity per second.

If this determination is made at different seasons, it is found that the velocity is greater in summer than in winter. At the temperature of freezing water, or 0° Centigrade, the velocity of sound in air is 332.4 m., or 1090.5 ft., per

second. The velocity at any temperature, in meters per second, may be found by substituting the reading of the Centigrade thermometer for t in the following formula:

$$v = 332.4 \sqrt{1 + .003665\, t}. \tag{41}$$

EXAMPLE. — Find the velocity of sound when the thermometer reads 26° Centigrade.

$$\begin{aligned} v &= 332.4 \sqrt{1 + .003665 \times 26} \\ &= 332.4 \sqrt{1.09529} \\ &= 332.4 \times 1.046 = 347.69 \text{ meters per second.} \end{aligned}$$

If the distance is required in feet, it can be found by substituting 1090.5 for 332.4 in Formula 41.

For approximate calculations the increase in velocity due to a rise in the temperature may be taken as 0.6 m. or 2 ft. per degree Centigrade, and 0.33 m. or 1.1 ft. per degree Fahrenheit. For most purposes the approximate results are sufficiently accurate.

199. The Velocity of Sound in Any Medium *is directly proportional to the square root of the elasticity of the medium, and inversely proportional to the square root of its density.* By using a proper numerical value for elasticity (Formula 1), the velocity of sound can be calculated from the equation

$$v = \sqrt{\frac{\text{elasticity}}{\text{density}}}. \tag{42}$$

The velocity of sound in air is increased by a rise in temperature, chiefly because heat causes air to expand, and thus decreases its density.

200. The Velocity of Sound in Liquids varies according to the above law. The velocity of sound in water has been measured directly in much the same way as the velocity in

air. A bell was struck under water in the Lake of Geneva, and a quantity of powder was fired at the same instant. An observer, at a station 8 miles away, measured the time that elapsed between the flash and the instant when the sound of the bell was received through the water. The velocity was found to be 4.3 times the velocity in air. Not only is the velocity greater in water than in air, but sounds are transmitted more distinctly. This fact is made use of by submarine boats in communicating with ships and other submarines, by under-water signals.

201. The Velocity of Sound in Solids is so great that in measuring it directly the stations must be far apart. Measurements have been made, however, and the velocity in copper has been found to be about 11.1 times as great as in air, and in steel wire 15 times as great.

If the ear is placed close to a long wire, or to a rail of a railroad, a blow struck upon the wire or rail at a distance will be heard twice, first through the solid, and then again through the air.

202. The Reflection of Sound. — In the first demonstration in § 196 the longitudinal wave sent along the spring is reflected from the fixed end. Sound vibrations are reflected in a similar manner. The law of reflected motion (§ 65) holds true for reflected sound. A good illustration of reflected sound is obtained by standing in a circular archway with the head in the center of curvature of the arch, and making a slight hissing sound. The sound will be reflected to the ear from all points of the arch and will be much increased in volume.

203. Echoes. — The repetition of a sound through reflection from any surface is called an *echo*. The distinctness

of the echo depends upon how fully the sound is reflected, while the length of the sound that can be repeated depends upon the distance of the reflecting surface. If it takes one second to pronounce a word, and if the speaker hears the echo as soon as the word is pronounced, his distance from the reflecting surface is about 166.2 m. (one half of 332.4 m.), since in that case the sound must go from the speaker to the reflecting surface and back in one second. If a single syllable is pronounced in one fifth of a second, the surface must be at least 33.24 m. away to produce a distinct echo. There are several noted examples of echoes in the hall underneath the dome of the capitol in Washington.

204. Multiple Echoes. — When a sound is made between two parallel cliffs, the echo may be repeated many times, thus forming a *multiple* echo. Two stones sharply struck together between two parallel buildings will produce a rattling sound like hail, if the buildings are the right distance apart (about 50 feet). A cornet, sounded in a deep valley between steep hills, will give rise to a series of musical echoes that gradually decrease in intensity and finally cease.

Questions

1. What is a simple harmonic motion?
2. What is the difference between a longitudinal and a transverse vibration?
3. Define wave length.
4. Is every vibrating body a sounding body? Explain.
5. Why is sound carried more rapidly by solids than by gases?
6. Why does sound travel in air more rapidly when the temperature rises?
7. When the wind blows over a field of grain a series of waves is set up. Describe the motion of the waves and of the heads of grain.
8. What would be the wave length in Fig. 187 if the distance between particles 1 and 7 were 8 ft.?

9. Let L = the wave length of a given sound, N the number of vibrations per second, and v the velocity per second. Write three equations, giving the value of each element in terms of the other two.

10. How do fishes hear?

11. Why is it sometimes difficult for a good speaker to be heard in a public hall?

12. How may the difficulty be partially removed?

Problems

1. What is the velocity of sound in air when the temperature is 23° C.?

2. How great a distance will the sound of a whistle go in 3 seconds when the temperature is 20° C.?

3. A man is seen chopping wood and the sound of the blow is heard one half second after the ax is seen to strike. How far away is the wood chopper if the temperature is 14° C.?

4. A mail tube in a certain city became clogged and a pistol was fired at the open end of the tube. The report came back from the obstruction $1\frac{1}{2}$ seconds afterward. How far from the open end was the pipe stopped, the temperature being 18° C.?

5. How long after a blast is set off in a quarry will the report be heard at a point 8500 ft. distant, the temperature being 22° C.?

6. The smoke from an exploding bomb used in day fireworks was observed, and after an interval of 9.4 seconds the report was heard. What was the distance, the temperature being 24° C.?

7. Five seconds elapsed between the firing of a gun and its echo from a cliff. What was the distance of the cliff, the thermometer reading 20° C.?

8. A blow, struck with a hammer on the rail of a railroad, was heard through the rail in one fifth of a second, and then through the air 2.8 seconds later. The temperature was 18° C. How far away was the blow struck? What was the velocity of sound in the rail?

9. The report of the explosion of a submarine mine 10 miles away was heard through the water in 11 seconds. How many times greater was the velocity in the water than that in the air at 12° C.?

10. Thunder is heard just 11 seconds after the lightning flash is seen. The temperature being 23° C., what was the distance?

II. INTERFERENCE, RESONANCE, AND MUSIC

205. Interference in Wave Motion. — **Demonstration.** — Repeat the demonstration of § 189, showing a transverse wave set up in a wire spring by a light blow. Just when the wave is reflected from the fixed end of the coil, strike a second blow: the direct and reflected waves will meet, and there will be some one part of the spring where the tendency of one wave to raise the spring will be exactly balanced by the tendency of the other wave to lower it.

This effect is called *interference*. Interference is a phenomenon attendant upon all wave motion, and arises from the fact that a medium that will transmit one wave motion will also transmit others at the same time. If the resultant of all the forces acting upon a particle at any time is zero, the result will be no motion, or interference. Interference in sound waves produces silence.

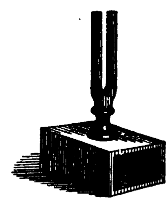


FIG. 188

Demonstration. — Sound a tuning fork, — preferably one with a sounding box, as in Fig. 188, — and move it rapidly toward, and then away from, a smooth wall. Observe the interferences that take place.

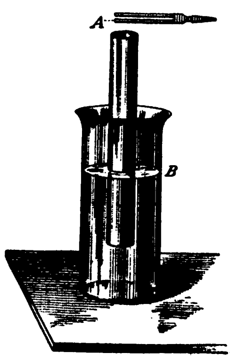


FIG. 189

206. Resonance. — When two waves act in the same direction upon a particle, they cause it to vibrate with greater amplitude. The resulting amplitude is the sum of the amplitudes of two waves. Such an effect in sound waves gives rise to a reënforcement of the sound, called *resonance*.

Demonstration. — Fill a tall glass jar nearly full of water, and get a piece of large glass tubing about a foot long, or the chimney of a student lamp. Hold a sounding

tuning fork over the upper end of the tube, and push the lower end into the water, as shown in Fig. 189, until the air in the tube responds to the tone of the fork and strengthens it.

207. Principle of the Resonator. — The tube in the above demonstration is called a *resonator*. While the prong A is producing a condensation on one side, it is producing a rarefaction on the other. In order that the sound of the fork may be strengthened by the resonator, it is necessary that the condensation started by the prong A in its downward vibration (Fig. 189) shall go to the bottom of the tube, which is the surface of the water at B, and be reflected to A in time to join the condensation produced by A in its upward vibration. If, instead, the distance AB is such that the reflected condensation meets a rarefaction, the result will be interference instead of resonance, and the sound of the fork will be weakened.

208. Relation of Velocity, Number of Vibrations, and Wave Length. — When a body is sounding continuously, the air be-

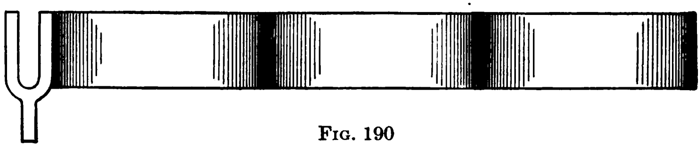


FIG. 190

tween it and a person who hears it is filled with a continuous series of waves.

The condensations are a wave length apart, consequently the wave length may be defined as the distance the sound travels while the vibrating body is making one complete vibration. The number of these waves that strike the ear each second will depend upon the rate of vibration of the sounding body, and the velocity of sound in the air

will be the product of the wave length by the number of vibrations per second. That is,

$$v = NL. \quad (43)$$

For example, if the wave length is 4 ft. and the vibrating body sends out 280 waves per second, then the front of the first wave will be 1120 ft. away from the sounding body when the 280th vibration is finished.

209. Measurement of the Velocity of Sound by a Resonance Tube. — It is possible to compute the velocity of sound in air by measuring the length of the air column in the resonance tube, and combining this properly with the number of vibrations per second. A convenient form of tube and support for this measurement is shown in Fig. 191. The glass tube A is connected by a flexible rubber tube to a similar glass tube fastened to the movable wooden arm B. This arm moves with so much friction that it will stay in any position. The support for the tuning fork is so arranged that forks of various lengths may be held in position. By pouring water into the tube and moving B toward or from the vertical position, the length of the air column in A can be so fixed that it will give a maximum reënforcement to the sound of the fork. When this is carefully determined, the length of the air column can be read on the millimeter scale

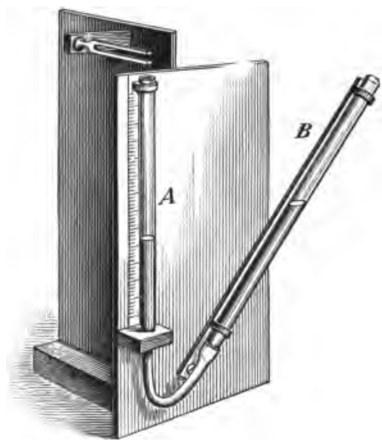


Fig. 191

back of A, which is graduated from the position of the fork as zero. To find the velocity of sound from this measurement it must be remembered that since the pulse of air first given out by the fork must go to the bottom of the tube and back, that is, twice the length of the tube, while the fork is making half of a complete vibration, it will go four times that length while the fork is making a complete vibration. This means that *the wave length of the fork is* 4 *times the length of the air column.* Calling the length of the air column l and substituting the value $4\,l$ in Formula 43, we have $v = 4\,lN$. Experiments with tubes of different diameters, however, show that a correction must be made for the diameter; that is, in order to get correct results a certain fraction of the diameter must be added to the length of the air column to give one fourth of the actual wave length. Lord Rayleigh finds this fraction to be nearly four tenths the diameter. Including this correction in the formula, we have

$$v = 4\,N(l + 0.4\,d). \qquad (44)$$

210. Sympathetic Vibrations. — Whenever a sounding body is near another that has the same time of vibration, it is found that the pulses of air sent out by the first will put the second in motion.

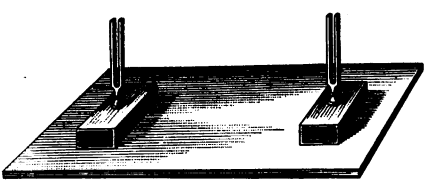


Fig. 192

Demonstration. — Select two tuning forks that are mounted upon resonance boxes, and that give the same number of vibrations per second. Place them parallel to each other at opposite ends of a table, and put one of them in vibration with a heavy bow. Stop its vibrations with the fingers, after a few seconds, and the second fork will be heard. Its vibration may also be shown by sus-

pending a light ball by a thread so that it will just touch one side of the fork.

The minute and rapid blows of the condensed waves of air striking upon the fork have enough energy to set it in motion, provided that the rate of the blows is the same as that of the vibrations. That this is also the case with a heavy swinging body may be shown as follows:

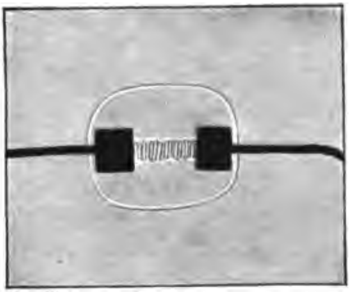
Demonstration. — Suspend from a hook in the ceiling a 20-pound weight, and find the time in which it will vibrate as a pendulum. Strike the weight light blows with a cork hammer, when it is at rest, timing the blows to the same rate as that in which it vibrated. If the blows are given at the right times, the result will be to set the pendulum swinging.

211. Forced Vibrations. — **Demonstrations.** — Hold a toy music box in the hand and play it. Place it upon a table and play it. Hold it against the glass door of a bookcase and play it. Describe the differences in the effects.

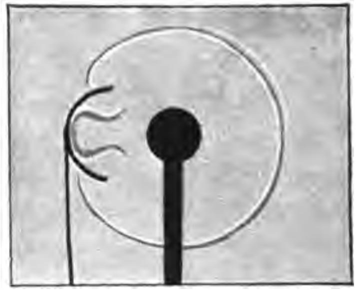
When the music box is played upon the table, there is a greater volume of sound because the vibrations of the box are communicated to the table top and put it in motion although their rates of vibration are different.

Since all the tones played are increased in volume, it is evident that certain parts of the table were forced to vibrate in time with the tones given by the box. If the end of a vibrating tuning fork is pressed upon a table, the sound will increase in volume but will soon die out, showing that the energy of the fork is rapidly used up in making the table vibrate.

A thin tone is produced by any vibrating body that puts only a small quantity of air in motion. Fullness of tone can be secured only by putting a large mass of air in motion. For this reason, in all stringed instruments, as the violin,

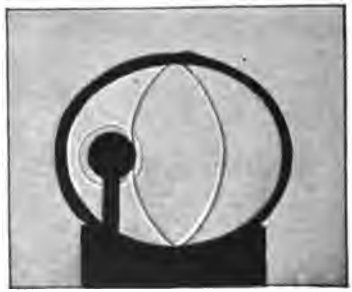


Section of a sound wave from an electric spark



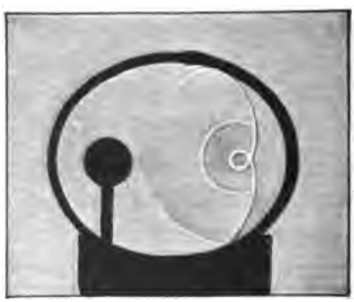
Sound wave reflected from a concave cylindrical reflector

Sound wave reflected by an elliptical mirror, first position



Sound wave reflected by an elliptical mirror, second position

Sound wave reflected by an elliptical mirror, third position



Sound wave reflected by an elliptical mirror, fourth position

Fig. 193. — Photographs of cylindrical sound waves made by Professor Arthur L. Foley and Mr. W. H. Souder, Indiana University. The source of sound was an electric spark, directly behind the black center and perpendicular to the page. Used by permission. (p. 208)

the guitar, and the piano, the strings are fastened to posts in a sounding board or wooden resonator box.

212. Beats. — When two sounding bodies that have nearly the same time of vibration are sounded together, the alternate interference and coincidence of the sound waves produce rhythmical variations in the intensity of the sound. These are called *beats* and can be readily heard.

If the waves sent out by the two sources are represented by the curves in the upper part of Fig. 194, we can see that one body must vibrate ten times while the other vibrates eleven. This means

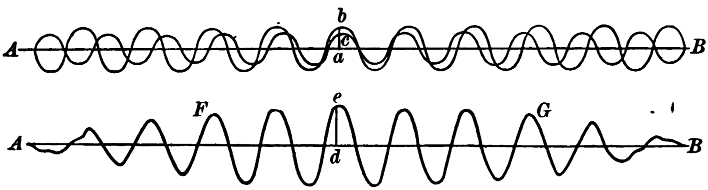


Fig. 194

that at every tenth wave of one, and every eleventh wave of the other, the waves will interfere, while at times midway between the waves will assist each other. The curve resulting from these two sets of waves is shown in the heavy line. The beat would come between F and G, at that part of the curve which swings the greatest distance from the straight line AB, while at A or B, where the interference is nearly complete, there would be very little sound. The heavy curve is constructed as follows: draw a set of vertical lines across the straight line AB; then any point e on the curve will be found by making de equal to the sum or difference of ab and ac, depending upon whether they are upon the same or opposite sides of AB. It is evident that in order to make a curve that will represent several beats between two musical sounds, a much more extended drawing would be required.

If two tuning forks, giving 128 and 129 vibrations per second respectively, are sounded together, they will be in

the same phase once per second and in opposite phases a half second later. This combination gives one beat per second. If a fork giving 130 vibrations is sounded with the one giving 128, they will be in the same phase twice per second and in opposite phases a quarter second later, and there will be two beats per second. By vibrating together forks with greater differences in the number of their vibrations, it is seen that *the number of beats between two sounds is equal to the difference between the numbers of their vibrations per second.* This can be demonstrated by the use of two forks that vibrate in the same time. By pressing a piece of beeswax upon one prong of one of these forks, it can be made to give fewer vibrations, and a beat will be heard when the forks are sounded together. By increasing the load, pressing a shot into the wax if needed, a greater number of beats per second will be produced.

213. Properties of Musical Tones. — In order that a vibrating body may produce a musical tone, its vibrations must be *rapid, continuous,* and *isochronous.* A musical tone may be a *simple tone,* in which the vibrations are all alike, or it may be a *compound tone,* formed of a combination of two or more vibrations. A *noise* differs from a musical tone in being formed by a mixture of a great variety of vibrations that cannot be resolved into simple ones. A tuning fork gives a simple tone; a piano string, a compound tone; and the fall of a pile of lumber, a noise.

The principal characteristics of musical tones are *intensity, pitch,* and *quality.*

214. Intensity. — The intensity of a sound depends upon three things: the amplitude of the vibration producing it, the area, and the distance at which the sound is heard.

(*a*) *Amplitude.* — When a tuning fork is struck, the energy which it can impart to the air will depend upon the extent of its vibrations. If these are slight, only a weak tone is produced. Strike a harder blow, and the amplitude increases, the energy the fork can give to the air is greater, and the sound is louder. The relation between amplitude and intensity may be readily shown by substituting a tuning fork for the whalebone in the demonstration in § 190. Make a number of traces on the glass when the fork is sounding at different intensities, and compare them.

(*b*) *Area.* — A small tuning fork, on being put into vibration, sets only a small quantity of air in motion and gives a sound having but little intensity; but if the prongs are broad, the amount of air put in motion is greater and the sound is louder.

(*c*) *Distance.* — Since the sounding body is sending out waves in every direction, the sound wave is the outside of a spherical shell of which the body is the center. The shell of molecules to be vibrated becomes larger and larger as the sound wave passes out from the center, and hence the energy that can be imparted to each air molecule becomes less and less. The intensity of sound depends directly on the amount of this energy.

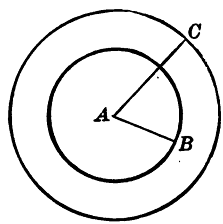


FIG. 195

Suppose a source of sound is at the point *A*, Fig. 195. Suppose this to be the center of a spherical shell of which the radius is *AB*: the wave of sound produced by the sounding body will be received all over the surface of the sphere. If now this sphere is replaced by a larger one, of which the radius is *AC*, the same sound wave will be received over the larger surface and the intensity of

the sound on each unit of area of this surface will be decreased.

The areas of these surfaces are directly proportional to the squares of their radii; hence we may write: *the intensity of sound varies inversely as the square of its distance from the sounding body.*

If the waves of sound can be kept in one direction, as by being reflected from the inner surface of a tube, the intensity at any point will be greater and they will go much farther. Speaking tubes are made on this principle.

215. Pitch. — *The pitch of a tone depends upon the number of vibrations made per second by the vibrating body that produces it,* the pitch being relatively high when the vibrations are rapid, and low when they are slow.

Since the velocity of sound is the product of the wave length and the number of vibrations per second, it is evident that the wave length is greater for tones of a low pitch than for those of a high pitch. It is also evident that as the *period* (or length of time of one vibration) becomes greater the pitch becomes lower.

When the corner of a stiff card is drawn across the cover of a cloth-covered book, a certain sound will be heard. On moving the card more rapidly, the pitch of the sound produced is made higher than at first.

The speed at which a circular or "buzz" saw is running can be judged by the pitch of the tone which it gives when sawing a log. A knot in the log lessens the speed and lowers the pitch of the tone.

216. The Siren. — The name *siren* is given to an instrument used to determine the number of vibrations required to produce tones of different pitch, as well as to show the re-

lation between them. A simple form and the method of using it are described in the following:

Demonstration. — Cut out a disk of bristol board, or, better, of some thin metal, 30 cm. in diameter. From the center describe four concentric circles, with diameters of 28, 24, 20, and 16 cm. respectively. Divide these circles into 32, 24, 20, and 16 parts respectively, and drill holes 6 mm. in diameter through the disk at these points.

Fig. 196. — Siren

Fit the disk to a rotating machine. Into each end of a rubber tube fit a glass tube; and holding one end directly opposite to one row of holes, put the disk in rotation and blow through the tube. If the rotation is begun very slowly, the separate puffs of air can be heard as they go through the holes in the disk and are then cut off; but if the speed is increased, the puffs will link themselves into a musical tone and the pitch will continue to rise as long as the speed is increased.

Rotate the wheel with uniform velocity and blow through the holes in the different circles, beginning with the smallest and going to the largest. Is the result pleasing? Describe it. Compare with the effect produced by blowing through all four at once.

A little practice will enable one to turn the handle of the wheel uniformly. By counting the number of turns given to the handle per minute the number of rotations of the siren wheel can be found. The product of the number of rotations of the siren wheel per second by the number of holes in the circle used will give the number of vibrations per second for the tone produced.

217. Doppler's Principle. — When both the sounding body and the ear that hears the sound are stationary, the number of waves that strike the ear per second is the same

as the number sent out by the vibrating body; but if either is moving from a position of rest, either toward or away from the other, the number of vibrations that reach the ear per second, and consequently the pitch of the tone heard, are changed.

If N represents the number of vibrations of the sounding body, L the wave length, and d the distance over which the ear moves toward it in one second, then the number of vibrations heard by the ear will be $N + \frac{d}{L}$, and the pitch will be raised. The sounding body may itself be moving, or both it and the ear may be moving. If the distance between the bodies is increasing, let d represent the increase per second; the number of vibrations received will be $N - \frac{d}{L}$ and the pitch will be lowered. A good example of this effect is noticed when two trains pass each other while the engine bells are ringing. A man standing by the roadside notices that the pitch of the horn of an approaching automobile is higher than it is after the machine has passed.

218. The Musical Scale. — A tone with double the number of vibrations of another tone is called the *octave* of the other (from Latin *octavus*, meaning "eighth"), since it is the eighth tone in what is called the *diatonic scale*. The eight tones in the diatonic scale have received names and are represented by *notes* placed in certain positions with respect to a series of five parallel lines called a *staff*. These names and positions are shown below, where a tone of 256 vibrations per second (called middle C or c') is taken as the first tone of the scale. A tone and its octave resemble each other closely, and have the same name.

Staff and position . . . .

Number in scale	1	2	3	4	5	6	7	8
Letter names	c'	d'	e'	f'	g'	a'	b'	c''
Syllable names	*do*	*re*	*mi*	*fa*	*sol*	*la*	*ti*	*do*
Relative number of vibrations . .	256	288	320	341.3	384	426.6	480	512
Ratio of vibrations	1	$\frac{9}{8}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	2
Intervals		$\frac{9}{8}$	$\frac{10}{9}$	$\frac{16}{15}$	$\frac{9}{8}$	$\frac{10}{9}$	$\frac{9}{8}$	$\frac{16}{15}$

219. The Scale Extended. — The scale is extended into higher pitches by taking the *do* of 512 vibrations as 1, and multiplying this number by the ratios of vibrations. The letter names are c'', d'', etc., and the syllable names, *do, re,* etc., as before. The next octave below is found by taking the *do* of 256 vibrations as 2. Hence the *do* an octave below has 128 vibrations, and from this as 1 the vibrations can be determined for any tone. These tones are called *c, d,* etc., and *do, re,* etc.

220. The Major Chord. — The scale given in § 218 is the *major scale* formed upon the *major triad* or *major chord.* This chord consists of any three tones, the numbers of whose vibrations per second are in the proportion of 4, 5, 6. There are three major chords, as follows:

$$\begin{aligned} \text{Tonic} &= c' : e' : g' = 4:5:6 \\ \text{Dominant} &= g' : b' : d'' = 4:5:6 \\ \text{Sub-dominant} &= f' : a' : c'' = 4:5:6. \end{aligned}$$

The names of the first tones of these chords will suggest the origin of the name of the *Tonic sol fa* system of musical notation. It will also be observed that these three major chords include all the tones of the major scale.

221. Intervals in the Scale. — The series of ratios 1, $\frac{9}{8}$,

$\frac{5}{4}$, $\frac{4}{3}$, etc., that express the relative numbers of vibrations also express the *intervals* between the *do* and other tones of the scale. The most important of these intervals in the major scale are the *major third*, $\frac{5}{4}$, or *do* to *mi;* the *fifth*, $\frac{3}{2}$, or *do* to *sol;* and the *octave*, $\frac{2}{1}$, or *do* to *do*.

222. The Keynote. — The note which is taken as the *do* or 1 of any scale is its *keynote*, and the tone it represents is the *key tone* or *tonic* of the scale. The scale already considered has c' for its keynote and is in the key of C. Suppose we form a major scale with g' for its keynote and compare the numbers of vibrations in its various tones with those in the key of C.

	g'	a'	b'	c''	d''	e''	f''	g''
Key of C . . .	384	$426.\dot{6}$	480	512	576	640	$682.\dot{6}$	768
Key of G . . .	384	432	480	512	576	640	720	768

We see by this comparison that there are two tones each represented by a' and f'', which differ in the number of their vibrations. The interval for the two a''s is $432 : 426.\dot{6}$, or $81 : 80$. This is called a *comma*. The f'''s differ more widely, their interval being $135 : 128$. This is sometimes called a *semitone*. In order to play music accurately in the key of G, two tones that are not found in the key of C would be required. One of these, the f'' of the key of G, is introduced approximately by increasing the vibrations of f'' in the key of C by multiplying the number by $\frac{25}{24}$; this new tone is called f'' *sharp* or $f''\sharp$. The number of vibrations for a' in the key of G differs so little from that of the same tone in the key of C, that in most instruments one tone serves for both.

Inasmuch as any tone in any scale may be taken for a new key tone, it is evident that to introduce two new tones for every new scale on such an instrument as the piano would

make the keyboard so large that it could not be used at all. Other complications come in also when the *flat keys* are used. In these (for instance, in the scale formed with f' as the key-note) the new tone required by the ratio of vibrations is secured by lowering the number of vibrations of the corresponding tone by multiplying it by $\frac{24}{25}$. The resulting tone is called the flat of the first, as *b flat* or $b\flat$. Between c' and d' there would be two tones, as follows: c', $c'\sharp$, $d'\flat$, d', having for their respective vibrations, 256, 266.6, 276.5, 288.

223. Chromatic Scale; Equal Temperament. — In practice there is but one key on the piano between C and D, and this is called either $C\sharp$ or $D\flat$. In addition to the eight tones of the major diatonic scale, there are five flats or sharps, and all thirteen together, when played in order, constitute the *chromatic scale.* The system adopted to fix the number of vibrations for each of the thirteen tones of each octave on the piano is called the system of *equal temperament.* The twelve intervals (semitones) in the scale are made equal, and this interval is $\sqrt[12]{2}$, or 1.05946^{+}. This means that the number of vibrations of any of these thirteen tones is obtained by multiplying the number of vibrations of the preceding one by 1.05946.

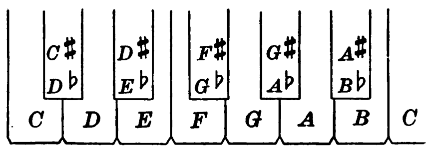


Fig. 197

Figure 198 shows graphically the difference between the equally tempered scale and the scale with sharps and flats given their true vibration numbers, for the octave beginning with $c' = 256$ vibrations and extending to $c'' = 512$ vibrations. A skilled violin player with a well-trained ear will

play the true intervals of the scale. This is one reason why the music of a string quartet is very pleasing.

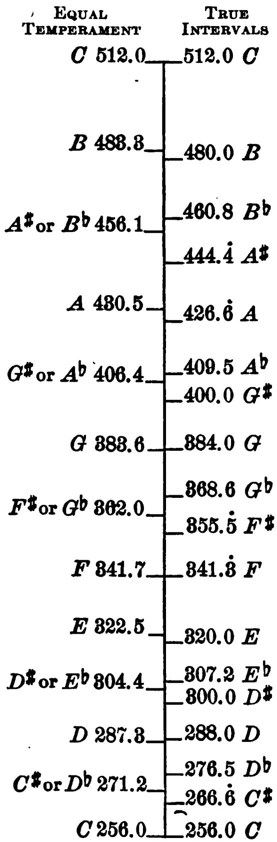


FIG. 198

224. Quality or Timbre. — When we hear a musical sound, we have no difficulty in recognizing the kind of instrument that produces it. The sound of the violin, of the piano, of the cornet, has each its own peculiarity. One voice is full and rich, another is thin, and another is monotonous. The characteristics which enable us to assign a sound to its source are called the *quality* of the tone. The physical explanation of quality is that most sounding bodies vibrate not only as a whole, but also in various parts, as does the string of a piano, and that a sound is rich in quality when it contains various *overtones* produced by these partial vibrations, as well as the fundamental tone of the vibrating body.

The wave form of a tone which is rich in quality is a complex one. Besides the full length wave given by the fundamental tone, there is one $\frac{1}{2}$ as long, given by the first *harmonic*, one $\frac{1}{3}$ as long, given by the second harmonic, and so on. For example: If the fundamental is c', the first harmonic is c'', the second is g'', the third is c''', etc.

225. Harmony and Discord. — Two musical sounds are said to produce *harmony* when, on being sounded together, they produce a result pleasing to the ear. If the result is displeasing, they are said to produce *discord.* One cause of discord is the presence of beats between the two tones, and the greatest discord, between tones of medium pitch, results when the beats are about 32 per second; if the number of beats is fewer than 10 or greater than 70 per second, they are somewhat unpleasant but do not produce discord.

Questions

1. Under what conditions will two wave motions completely neutralize each other? What will be the result if they are water waves? What if they are sound waves?

2. If a tuning fork is put in vibration and then rotated while it is held near the ear, there will be four times per rotation when it can hardly be heard. Explain.

3. If a tuning fork is held over the mouth of a resonator, while vibrating, and slowly rotated, a point can be found at which there is practically no resonance. When a tube is slipped over the upper prong, without touching it, the sound of the resonator will again be heard. Explain.

4. Why cannot one fork be set in motion by another unless its rate of vibration is the same?

5. Why do soldiers break step on crossing a bridge?

6. Why does an auto horn seem to have a higher pitch before you meet it than after it has passed?

7. Why does the chord *do, mi, sol,* have a richer sound than either of the tones alone?

8. How many keys would it require for an octave on the piano if the sharps and flats were not played on the same key?

9. Does a violin player in a string quartet play the equally tempered or true interval scale? Why?

10. Why does a singer sometimes prefer the piano accompaniment to a song to be played in the key of three flats instead of in the key of four sharps?

Problems

1. The air column of a resonance tube which gives the maximum reinforcement to the sound of a tuning fork is 12.5 in. Find the wave length of the fork. (A correction for the diameter of the tube need not be made.)

2. A tuning fork gives 384 vibrations per second. What must be the length of a resonating tube for it at a temperature of 0° C.?

3. What is the velocity of sound, determined by the apparatus shown in Fig. 191, when the resonator tube is 22 mm. in diameter and 248.5 mm. long, if the fork makes 320 vibrations per second, the temperature being 0° C.?

4. Two tuning forks vibrate 126 and 128 times per second respectively. How many times per second do they reënforce each other?

5. Two tuning forks that give 260 vibrations per second are sounded together, showing by the absence of beats that they are in unison. One of them is now loaded until five beats are heard per second. How many vibrations does it now give?

6. Suppose the inmost row of holes in the siren described in the demonstration in § 216 gives the tone $c' = 256$ vibrations. How many times does the disk rotate per second? What tones will the other rows of holes give?

7. What change in the speed of the siren disk must be made to lower the tone an octave?

8. A person in an automobile that is being driven at the rate of 25 miles per hour blows a whistle that gives 320 vibrations per second. How many vibrations per second will reach the ear of a man standing by the roadside, first, *before*, and second, *after* it has passed, if the temperature is 20° C.?

9. If c' has 256 vibrations, show how to find the number of vibrations in d' and e' as played on the violin; on the piano.

10. Show why a tone must be introduced into the scale of the key of *G* that cannot be found in the scale of the key of *C*.

11. In the time of Handel the standard a' fork gave 424 vibrations per second. The present international a' fork gives 435 vibrations. What effect does this have upon the difficulty of singing the high notes of a song written by Handel?

III. VIBRATION OF STRINGS, AIR COLUMNS, ETC.; COMBINATION OF VIBRATIONS

226. The Sonometer. — To investigate the laws of the vibration of strings an instrument called the *sonometer* is used. This is also called a *monochord*, since it often has but a single string. The essential parts are a base with a bridge at each end, a pin to which to fasten one end of the string, and some method of stretching the string by attaching a spring balance

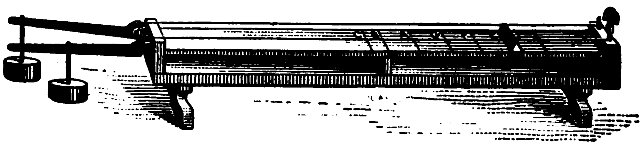


FIG. 199. — Sonometer with Two Strings

or weights at the other end. A movable bridge (at E in Fig. 199) is used to change the length of the vibrating string, and a scale is laid off on the base.

227. Laws of the Vibration of Strings.

I. *The tension and mass per unit length being the same, the number of vibrations per second varies inversely as the length of the string.*

II. *The length and tension being the same, the number of vibrations per second varies inversely as the square root of the mass per unit length of the string.*

III. *The length and mass per unit length being the same, the number of vibrations per second varies directly as the square root of the tension.*

The above laws can be expressed by the proportion

$$N : N' = \frac{\sqrt{T}}{l\sqrt{M}} : \frac{\sqrt{T'}}{l'\sqrt{M'}}.$$

For the first law, under the conditions given, the proportion becomes

$$N : N' = \frac{1}{l} : \frac{1}{l'}, \text{ or, } N : N' = l' : l.$$

If the length of a certain string is taken as unity the parts of the same string that give the other tones of the scale are as follows:

Syllable names: *do* *re* *mi* *fa* *sol* *la* *ti* *do*
Length of string: 1 $\frac{8}{9}$ $\frac{4}{5}$ $\frac{3}{4}$ $\frac{2}{3}$ $\frac{3}{5}$ $\frac{8}{15}$ $\frac{1}{2}$

It will be observed that these ratios which give the relative length of string are the reciprocals of the ratios giving the relative numbers of vibrations.

For the second law the proportion becomes

$$N : N' = \frac{1}{\sqrt{M}} : \frac{1}{\sqrt{M'}}, \text{ or, } N : N' = \sqrt{M'} : \sqrt{M};$$

and for the third law, $N : N' = \sqrt{T} : \sqrt{T'}$.

These laws can be verified on the sonometer.

The strings of the piano illustrate the preceding laws. The lowest tones are made by long, heavy strings without great tension, while the highest tones are made by short, light strings stretched to a high tension.

228. Nodes and Loops. — **Demonstration.** — Hook one end of the wire spring as in § 189. Throw the coil into vibrations as a

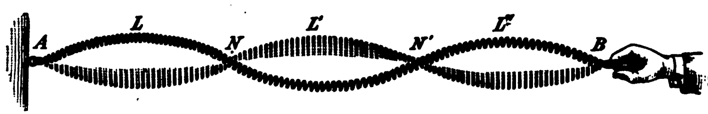


FIG. 200

whole by a slight movement of the hand. Quicken the movement, and it can be thrown into vibrations in halves, thirds, quarters, etc., giving a number of complete "stationary waves."

When the spring is vibrating as shown in Fig. 200, the points of no vibration are called *nodes,* as N, N', while the points of maximum vibration, as L, L', etc., are called *loops.* The vibrations are caused by waves sent out from A and reflected from B. Whenever the wave starting from A tends to give a certain velocity to any particle, and the reflected wave from B tends to give it an equal velocity in the opposite direction, the two forces neutralize each other, the particle remains at rest, and a node is formed.

When the string of a musical instrument is put into vibration by drawing a bow across it, by striking it a blow, or by plucking it, it vibrates transversely, not only as a whole, giving its fundamental tone, but also in halves, thirds, fourths, etc., each one of which gives its own tone. These different tones, with the fundamental, determine the quality of the tone.

Demonstration. — Place a wire, or heavy bass viol string on the sonometer and stretch it until it gives a suitable tone. Sound the fundamental tone with the bow. Touch the string lightly in the middle with the finger and draw the bow across the string one fourth the length of the string from the end. This will sound the octave. Touch the finger at one third the length of the string from the end. Draw the bow at one sixth and the note sounded will be the second harmonic, etc.

229. Overtones and Harmonics. — It is not necessary to touch the string in order to make it vibrate in parts besides vibrating as a whole. The tones caused by the vibrations in parts can be heard by listening carefully when the string is plucked. These tones are called *overtones,* and if the numbers of vibrations which produce them are 2, 3, 4, etc., times the number of vibrations of the fundamental, they are called *harmonics.* Overtones can be very readily pro-

FIG. 201

duced on a guitar and form the most accurate method of tuning it.

230. Nodes and Loops in a Bell. — **Demonstration.** — Mount a bell jar as in Fig. 201 and put it in vibration by striking it lightly with a cork hammer, or by drawing a violin bow across its edge. It will give out a bell-like tone. If the bow is drawn midway between two of the suspended balls, they will all remain in contact with the rim, showing the existence of nodes; but if one of the balls is raised and the bow drawn at the point where it rested upon the rim, the three other balls will be thrown into vibration, showing the position of the loops.

231. Vibration of Air Columns. — In most musical instruments called *wind instruments,* the tones are produced by the vibrations of columns of air, of different lengths. There are three classes of *mouthpieces,* by means of which the air is put into vibration in wind instruments.

FIG. 202

In the first class the air is blown across the sharp edge of an opening, as in the whistle, the organ pipe (Fig. 202), and the flute.

In the second class the air is blown past a thin, flat tongue called a *reed,* which by its vibration opens and closes the opening into the air column. The *striking* reed (Fig. 203, *A*), used in the clarinet, closes the opening by striking upon its edges; the *free* reed (Fig. 203, *B*), used in the accordion and reed organ, nearly closes the opening by vibrating back and forth through it.

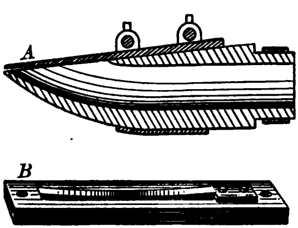


FIG. 203

In the third class of wind instruments the lips are generally used as vibrating membranes through which the air is blown into the instrument. Figure 204 shows the mouthpiece of a trumpet.

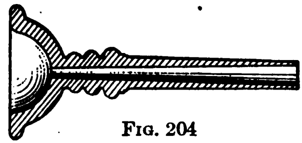


Fig. 204

232. Nodes and Loops in an Organ Pipe. — The vibration of air in a tube is in the direction of its length, but it can give rise to nodes and loops as well as a vibrating cord.

In this case, however, the node must be understood to mean a point where the particles of air remain at rest, but where there are rapid changes from condensation to rarefaction, and *vice versa.* A loop means a point where there is the greatest motion, but no change of density. From this it will be seen that the end of a closed pipe must form a node, and the end of an open pipe a loop. In *A* (Fig. 205), a node would be at the upper end and a loop at the mouth; consequently the length of a closed pipe is one fourth the wave length of its fundamental tone, as is the case in the resonator tube in §§ 207, 209. If the pipe is blown strongly, it will give out a tone higher in pitch, but a node will still be at the closed end and a loop at the mouth. In this case (*B*) there will be an intermediate node and loop at *N′* and *L′*, and the length of the pipe will be three fourths the wave length of the tone produced.

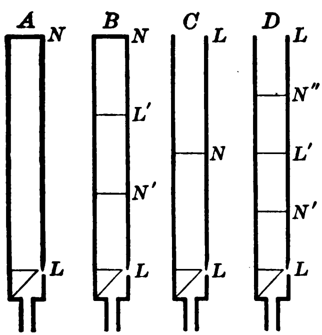


Fig. 205

In the open pipe, *C* (Fig. 205), there will be a loop at each end, and a node in the middle, and the length of the pipe

will be half the wave length of the fundamental tone. If the next higher tone is produced, there will be two nodes, N' and N'', and an additional loop L' and the length of the pipe will be equal to the wave length of the tone. Comparing A and C it will be seen that the fundamental tone given out by an open pipe is the octave of the tone produced by a closed pipe of the same length.

Fig. 206

Demonstration. — Procure an organ pipe, one side of which is glass, and lower into it, by a thread, a light ring over which is stretched a membrane with fine sand sprinkled over it, as shown in Fig. 206. When the fundamental tone is sounded and the ring is lowered, the sand will show by its movements that the amount of the vibration is decreasing until the middle of the tube is reached, where it will come to rest. Increase the force of the bellows that blow the pipe, so as to produce the higher tone; the middle point becomes a loop, as is shown by the dancing of the sand.

If an opening is made in the side of a pipe, this becomes a loop and changes the pitch of the tone produced. In this way the different tones of a flute are made by the fingers of the player stopping and unstopping holes along the side.

233. The Vibration of Rods and Tubes. — A rod fixed at one end may be put in transverse vibration by being struck or plucked at the free end — as in the music box. The longer the rod, the lower the tone produced.

Rods may be made to vibrate longitudinally as well as transversely.

Demonstrations. — Hold a glass rod, a meter long or more, by the middle with one hand, while with the other you draw a moist

cloth lightly from the middle to the end. The rod will be thrown into longitudinal vibrations, and the fundamental tone will be produced. Do the same with a wooden rod, a brass rod, and a brass tube of the same length and diameter, using a rosined cloth for a rubber. Does the pitch of the tone depend upon the material of the rod?

Repeat the above demonstration with two glass tubes of different diameters, but of the same length. Does the pitch of the tone depend upon the diameter of the tube? Repeat with one of these tubes and another of the same diameter but only half as long. Does the pitch depend on the length of the tube? How do the two tones compare?

The sound caused by rubbing the tubes and rods in the above demonstrations is due to longitudinal vibrations. That such vibrations exist may be shown as follows:

Demonstration. — Clamp a brass rod firmly to a block upon a table as shown in Fig. 207. Suspend an elastic ball so that it will rest against one end of the rod, and then draw a rosined cloth from the middle to the other end. The longitudinal vibrations will cause the rod to give out a high tone, and will repel the ball from the end of the rod.

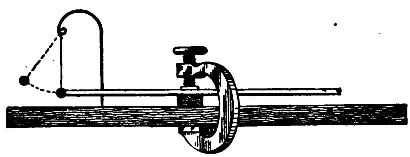


FIG. 207

The mechanical effect of vibrations in tubes is sometimes very great. It is not uncommon for a test tube to be cracked into a spiral ribbon running from end to end, on being wiped with a damp towel. If a glass bell jar is bowed vigorously a few times with a violin bow, it may be shattered even if the walls are a quarter of an inch thick.

234. The Vibration of Plates. — If a thin plate of metal or glass is clamped to a support at the middle, and a bow is drawn across its edge, it will be thrown into vibration

and will produce sound. The positions of the *nodal lines* of the plate can be shown very readily as follows:

Demonstrations. — Sift sand evenly over the surface of a brass plate fastened by the middle, as the first one in Fig. 208. Place a finger at one corner and draw a bow across the middle of one side. The sand will be thrown violently about, and will finally come to rest on those parts of the plate that do not vibrate, so that the lines of sand indicate the nodal lines. Figure 208 shows a number of plates

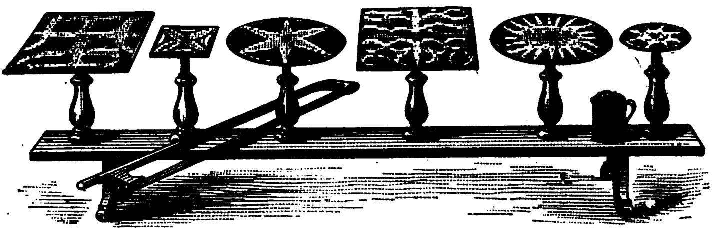


FIG. 208

differing in form, size, and thickness, and a few of the many interesting figures that can be produced by them. If the plates are clamped by the corner or at one side, a new set of figures will be obtained.

Scatter a little lycopodium powder on the plate with the sand, and it will be found, on vibrating the plate, that the powder will collect over the places of greatest vibration instead of at the nodal lines as the sand does. Examine carefully and explain why this happens.

235. Graphical Method of Combining Vibrations. — It is frequently desirable to represent graphically the relation that exists between the vibrations of tones of different pitches. The method usually adopted is to consider the vibrations of the two bodies to be made at right angles with each other, and to construct a curve that shall be the result of the two vibrations combined. If the vibrations producing the tones *c* and *f* are to be combined, the curve can be made graphically as follows:

Suppose a point moving back and forth along AC, in simple harmonic motion corresponding to uniform motion around circle H, to represent the vibrations that produce c, and suppose a point moving along AB in simple harmonic motion with reference to circle D to represent the vibrations that produce f (Fig. 209). Since the ratio of the numbers of vibrations in these two tones is $1 : \frac{4}{3}$, the body sounding the tone f vibrates eight times while the body sounding c vibrates six times, and therefore makes one sixth of a vibration while the body sounding c makes one eighth of a vibration. Lay off the circumference DEF into six equal parts, and the other circumference into eight. From the points of division draw lines perpendicular, respectively, to AB and AC, and prolong them; then their intersections will give the points for the required curve. In order that the curve connecting the points shall be smooth, intermediate points must be determined.

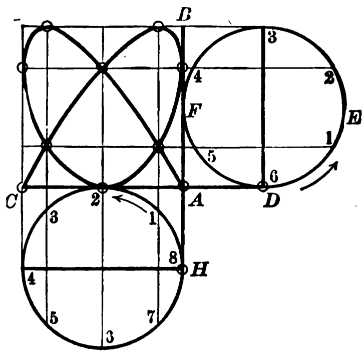


FIG. 209

The curve representing the combination of any other two tones can be constructed in the same way.

236. The Pendulum Method traces the curve.

Demonstration. — On the opposite sides of a baseboard, about 40 cm. square, fasten two uprights 102 cm. long above the upper surface of the base. Fix a crosspiece to the top of these. Bore a hole in the middle of this and fit a handle so that it will turn snugly. Make a lead disk 10 cm. in diameter and 2 cm. thick, and through the middle drill a hole 5 mm. in diameter. Suspend this by three

cords as in Fig. 210, and at the point A tie these three cords to two others which run through the holes B and C in the crosspiece and then through a hole in the handle H. Wind a ring of copper wire R about the two cords, so that it can be slipped up or down, and unite the two into one, as RA. Place a glass plate on the baseboard, and sift sand upon it from a tin flour dredge. Select a glass rod or tube that will slip easily through the hole in the disk, and make one end small and rounded in a Bunsen flame. Put the rod through the disk; then draw the disk back and release it so that it will vibrate across the base in the direction DE. The disk swings as a pendulum from the points C and B, and the rod traces a straight line in the sand. Vibrate again in a direction GF, at right angles to DE. The rod will again trace a straight line, swinging from the point R. Now draw the disk aside midway between these directions, and when it is released the rod will trace a curve which will be the result of combining the two motions, and the form of which will depend upon the relative lengths of the two pendulums, *i.e.* of the points K and R from the middle of the lead disk.

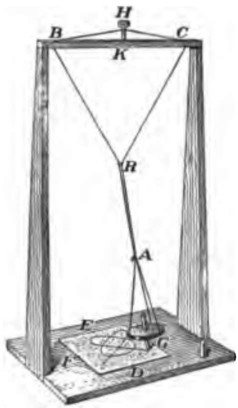


FIG. 210

The distance of K from the middle of the disk can be kept at 1 m. by turning the handle H; and by making the distance of R from the middle of the disk such that the short pendulum vibrates three times while the long one vibrates twice, the curve corresponding to the combination of the tones *sol* and *do* is obtained. If the times of vibration are as 2 : 1, the curve will represent the combination of a tone and its octave. By applying the law of the pendulum for length and time of vibration, the length of the short pendulum can be easily found for most musical intervals.

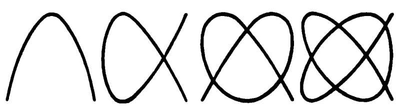


FIG. 211

Figure 211 shows some of the simpler figures that can be obtained if the ratios of vibrations are such as 1 : 2, 2 : 3, 3 : 4.

If the ratios are of large numbers, the figures become more complicated.

237. Manometric Flames. — The optical method devised by Dr. König, to which he gave the name of *manometric flames*, consists of bringing the condensations and rarefactions of sound waves to act upon a gas flame and regulate its height, and of observing the effect in a revolving mirror. The prin-

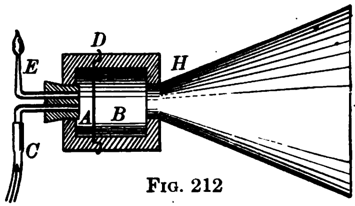


Fig. 212

ciple of the apparatus is shown in Fig. 212, and the complete form in Fig. 213. A wooden or metal box is divided into two chambers, *A* and *B*, by an elastic diaphragm *D*.

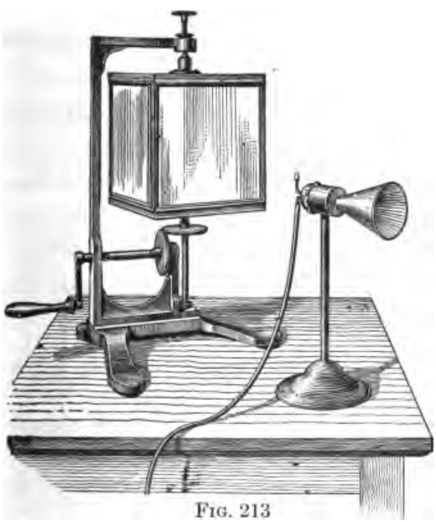


Fig. 213

Two pipes open into *A* and one into *B*. The pipe *C* brings in gas, which is burned as a small, round flame at the top of the tube *E*. The pipe *H* opens into *B* and conveys the sound waves made before its open end at *M*. When *D* is struck by a condensation, it bends toward *A*, making that chamber smaller, increasing the pressure, and making the flame burn higher at *E*. When a rarefaction comes to *D*, the chamber *A* is made larger, the pressure is decreased, and

the flame drops down to a shorter one. These changes follow one another so rapidly that the eye cannot detect them unless the image of each flame is separated from the others. This can be done in two ways: first, by turning the eye quickly and throwing the line of sight across the flame, when the images will be separated in the eye; and second, by the use of a revolving mirror. If the mirror is turned while the flame is burning steadily, the reflection of the flame seen in the mirror will be a plain band of light; but if a simple tone is sung into the mouth *M*, the rise and fall of the flame will show itself as a succession of pointed reflections of equal height, leaning in the direction opposite to the rotation of the mirror, as in Fig. 214, *A*. If now the octave of this tone is sung, the reflection will have twice the number of points. If the tone sung is accompanied by overtones, the reflection will show a compound form in which smaller waves are impressed upon the fundamental as in Fig. 214, *B*.

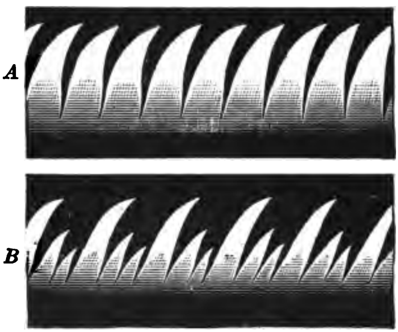


FIG. 214

NOTE. — Experiments with vibrating flames and rotating mirror will not give satisfaction unless carried on in a dark room.

Demonstration. — Sing the tones of the scale before the mouthpiece, calling each tone *O*. Notice the change for each pitch. Repeat with *do*, *re*, *mi*, etc. Can you tell a simple tone from a compound one?

238. Helmholtz Resonators are spherical shells, of various sizes, each having at one side a short tube to receive the

sound and directly opposite a smaller tube which is held to the ear. Each resonator will increase the loudness of a tone of some particular pitch only, whether that tone is a fundamental or an overtone. These instruments were devised by Helmholtz, and by their use he discovered just which overtones are present in the sounds of various musical instruments.

Fig. 215

A modified form of Helmholtz resonator is shown in Fig. 215. This consists of two tubes, one of which slides within the other so that the instrument can be adjusted to tones of varying pitches. The flexible tube is connected to the manometric flame apparatus, and by this means the character of the vibrations present is determined. By combining sounds giving all the different vibrations observed, it is possible to reproduce a sound having the same *quality* as the original.

239. Musical Flames. — The air in a tube may be thrown into sound vibrations by means of a small flame.

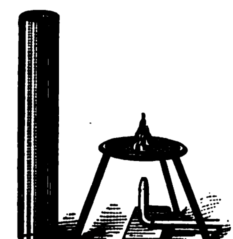


Fig. 216

Demonstration. — Procure a glass tube about 8 mm. in diameter and about 20 cm. long and draw it down to a small jet. Bend this tube at right angles and fasten it to a small board with a wire staple. Place this under a tripod covered with wire gauze, as shown in Fig. 216. Turn on the gas and light it above the gauze. Regulate the position of the glass tube and the pressure of the gas until you have a flickering blue flame, broad at the base and pointed at the top. Place over this a tube 5 cm. in diameter and of almost any

length, and it will at once give out a loud musical tone. Compare the pitches given by tubes of different lengths.

240. Sensitive Flames. — Demonstration. — Select a piece of small glass tubing and draw it to a point in the Bunsen flame, leaving a fine opening. Connect the other end, by means of a rubber tube, to a gas supply, and if you have the right size of hole in the tube, and the right pressure of gas, which is generally greater than city gas mains supply, you will get a long line of flame, as in *A* (Fig. 217), that is just on the point of flaring. Make any kind of a sharp sound, and the flame will at once drop down to the form of *B*, and will keep flaring in that form as long as the sound continues. A shrill whistle, the rattle of keys, or any hissing sound will produce the same effect, showing that this is a very *sensitive* form of flame. Does the rapid change in pressure at the mouth of the tube, caused by the waves of condensation and rarefaction due to the high pitch of these sounds, explain the action of the flame? Test this flame by giving a shrill whistle outside of the room when the door is closed.

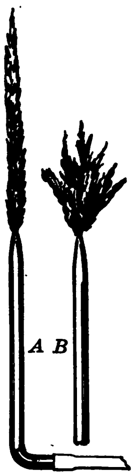


Fig. 217

241. The Phonograph, invented by Edison, consists of a cylinder of specially prepared wax upon which the vibrations of a diaphragm are recorded by means of a fine metal point or chisel attached to the diaphragm. The waves of sound throw the diaphragm into vibration, this sets the point in motion, and as the wax cylinder is rotated the point cuts a series of spiral grooves. These grooves are made up of minute indentations which correspond to the condensations and rarefactions of the sound waves. By means of a special form of point which takes the place of the cutting tool, and follows in the groove which it has cut, the sound can be reproduced with remarkable fidelity.

Other instruments for the reproduction of sound make use of a disk for the reproducing surface.

242. Limit of Audibility. — Every one knows that the range of voice differs for different people, one person singing tenor, another alto, and so on. There is a somewhat similar range in hearing, some ears being more sensitive to the high pitches, and some to the low.

Demonstration. — Procure a Galton's whistle, which consists of a small brass whistle with a rubber bulb at one end and a screw for adjusting the pitch at the other. Press the bulb when the screw is nearly out, and a rather low whistle will be heard. Turn in the screw a little, and sound again. The pitch is higher. In this way make the pitch steadily higher and higher, and it will be found that first one member of the class and then another will be unable to hear the whistle.

Fig. 218. — Galton's Whistle

Questions

1. Does it change the pitch of a sonometer string to draw the bow more vigorously?

2. Which string on a violin is the smallest? Why?

3. Why is the *G* string on a violin wound with wire?

4. What is the explanation of the cracking of a test tube by holding it at the top and drawing a damp towel from top to bottom?

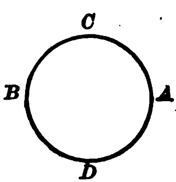


Fig. 219

5. Suppose Fig. 219 to represent the open end of a bell jar which is struck a light blow at *A* driving the rim toward the center. What will take place at the points *B*, *C*, and *D*, and where will the nodes be located?

6. Suppose you wish to produce a low tone on an organ pipe and you want the pipe to be as short as possible. Would you use an open, or closed pipe?

7. In what respects does the sound produced by a wooden organ pipe 1 m. long differ from that given by a metal pipe of the same length? In what respects is it the same?

8. Where does the sand collect on a vibrating plate? Why?

9. How would you establish the formation of a node in a vibrating plate?

Problems

1. If a sonometer string 1 m. long gives 128 vibrations per second, what must be the length of a similar string, stretched with the same weight, to give 192 vibrations? What tone will it give?

2. At what distance from the bridge of a violin must the finger be placed to produce the octave of the open string?

3. A string 1 m. long and 2 mm. in diameter makes 150 vibrations per second. Find the number of vibrations it will give if the length is doubled; if the tension is made 4 times as great.

4. What will be the length in cm. of the part of a string 1 m. long that will give each tone of the major scale?

5. What is the wave length of the tone of a closed organ pipe 3 ft. long? How long must an open pipe be to give the same tone?

6. How long must an open organ pipe be to give the octave of middle C at 0° C.?

7. How many vibrations will the pipe in problem 6 give if the end is closed?

8. What must be the length of the short pendulum of Fig. 210 to make the ratio of vibrations 3:2 if the length of the pendulum as a whole is 1 m.? What must be its length to give the ratio $C:E$?

9. What is the length of the air column in the Galton whistle, Fig. 218, when it gives 16,000 vibrations per second, the temperature being 20° C.? What is the wave length of the sound produced?

10. A steamboat whistle has a wave length of 34 ft. What tone does it give?

CHAPTER VII

HEAT

I. TEMPERATURE AND ITS MEASUREMENT

243. Heat a Form of Energy. — According to the modern *kinetic theory of heat,* the molecules of all bodies are in a state of rapid vibration, and any increase of the rapidity of this motion, from whatever cause, increases the heat of the body, while the heat is decreased if this velocity is diminished.

Heat is a form of molecular energy which may be produced by other forms of energy, and is itself convertible into other forms.

244. Temperature. — The terms "hot" and "cold" are purely relative. Whether one body is hotter or colder than another depends upon whether it can itself impart heat to the second body, or receive heat from it. The condition of a body in this respect is called its *temperature,* and depends directly upon its molecular kinetic energy. If m is the mass of one of the molecules of a body, and v its average velocity at a certain temperature, the expression for its molecular kinetic energy (Formula 20) is $\frac{1}{2}\ mv^2$. Hence the temperature of a body is directly proportional to the square of the average velocity of its molecules.

If one body is put into contact with another, the one that has the higher temperature will lose some of its heat, and the

one that has the lower temperature will gain heat, until they both finally come to the same temperature.

Temperature must not be mistaken for quantity of heat. A cup of hot water taken from a pailful will have the same temperature, but will contain very little heat in comparison with the water in the pail.

245. The Physical Effect of Heat upon Bodies. — There are two main results that may come from applying heat to a body. One is a change in its volume, and the other is a change in its physical condition.

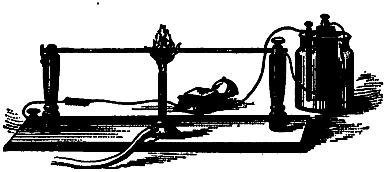


FIG. 220

Demonstrations. — Make a piece of apparatus like that shown in Fig. 220, as follows: Set two upright posts in a base-board. Bore in each post, near the top, a hole large enough to take a brass wire $\frac{1}{8}$ in. in diameter. Fasten one end of the wire to one post by a screw in the top and let the wire pass loosely through the other post. Connect a battery and electric bell with the wire, and let the other end of the circuit be connected with a thin brass spring just beyond the movable end of the wire. Adjust the spring carefully and bring the flame of a Bunsen burner against the wire. The heat will expand the wire, which will make contact with the spring, when the electrical circuit will be completed and the bell will ring. Remove the flame; the wire will contract, the contact will be broken, and the bell will stop ringing.

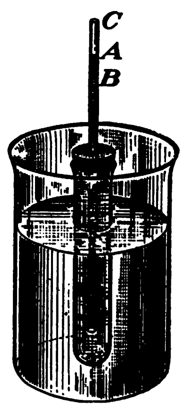


FIG. 221

Fit to the mouth of a test tube a rubber stopper with a single hole. Thrust a piece of glass tubing, about 30 cm. long, through the stopper. Fill the test tube with water and push in the stopper until the water stands at some point, as *A* (Fig. 221). Take the tube by the end

and lower the test tube into a beaker of hot water. The first effect is that the water in the small tube will drop to *B*. What is the cause of this? The second effect is that the water will then begin to rise and will finally run over the top *C*. Why?

Empty the test tube, and let it become dry and cool. Introduce a short column of water into the middle of the small tube, hold it in a horizontal position, and push in the stopper as before. Clasp the test tube in the hand and watch the position of the water index.

There are many practical uses of the expansion of solids when heated. A tire for a wooden wagon wheel is made of a size slightly smaller than the circumference of the wheel; to put it on, the tire is heated, driven into place on the wheel, and on cooling becomes small enough to be held very firmly. Large guns are built up by forcing heated steel rings over a steel core and letting them shrink on, after which the guns are bored out and rifled.

246. Measurement of Temperature. — The idea of the temperature of a body that we receive from our sensations is so dependent upon other things than the temperature, that it is frequently incorrect. What seems a high temperature to one person may seem a low temperature to another, and the same temperature seems different to us at one time from what it does at another. If one hand is wet and the other dry and both are held in the current of warm air coming from a register, the air will feel warm to the dry hand and cold to the wet hand. In this and similar ways we find that the body is not a good instrument with which to measure temperature. The instrument that is used for this purpose is called a *thermometer*. The principle employed is that of the unequal expansion of bodies when heated. The most common form is the mercury thermometer, which consists

of a glass tube with thick walls and a small bore, blown into a bulb at one end for holding the mercury.

247. Filling the Thermometer. — The air is partly driven from the bulb by heating it, the open end of the tube is put into mercury, and some of the mercury is driven into the bulb by the atmospheric pressure when the bulb cools. By repeating the process the bulb and tube are entirely filled. The mercury is then heated to a high temperature, and the tube is sealed at the top and left air-tight.

248. The Fixed Points. — Since the boiling point and the freezing point of pure water are always the same under the same pressure, these points are taken as the fixed points for the thermometer.

Fig. 222

The *freezing point* is determined by placing the bulb and part of the stem in snow or finely crushed ice, contained in a suitable vessel (Fig. 222). The point at which the end of the mercury column comes to rest, when close to the ice, is marked as the freezing point.

The *boiling point* is fixed by suspending the thermometer in the steam from boiling pure water. The bulb should be at least an inch above the water and the boiler should be tall enough so that the mercury will come only just above the stopper by which it is supported. Whenever the steam is coming briskly from the escape pipe and the mercury has ceased to rise, the end of the column is marked as the boiling point, provided the barometer reads 760 mm. at the time.

The manometer tube *m* (Fig. 223) shows whether the pressure of the steam is the same as that of the atmosphere. If this is not the case, a correction has to be made since the temperature of steam rises rapidly with an increase of pressure. When the pressure is near 760 mm., an increase of 27 mm. in the pressure produces a change of 1° C. in the boiling point.

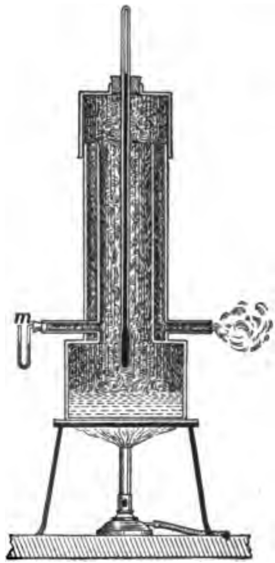


Fig. 223

249. Graduating the Scale.—The bore of the thermometer tube should be of uniform diameter throughout its length. At ordinary temperatures, equal increases of temperature will then cause practically equal amounts of elongation of the mercury column in any part of the tube; hence, when the kind of scale has been decided upon, the length between the freezing and boiling points is divided into equal parts, called *degrees*.

250. Thermometric Scales. — The scales in most general use in this country are the *Centigrade*, or hundred-degree scale of Celsius, which makes the freezing point of water zero (0°) and its boiling point 100°; and the *Fahrenheit*, which makes the freezing point 32°, the boiling point 212°, and puts the zero 32° below the freezing point. In both scales, readings that are below zero are designated by the minus sign, as − 10° C. The Fahrenheit scale is the one in common use in the United States, but the Centigrade has been adopted for scientific work on account of its greater convenience. Unless otherwise mentioned, the Centigrade scale will be used in this work.

251. Comparison of Centigrade and Fahrenheit Readings. — Since the Centigrade scale has 100 degrees between the fixed points, and the Fahrenheit 180, it is evident that 100 C. degrees = 180 F. degrees, and hence 1 C. degree = $\frac{9}{5}$ F. degree, and 1 F. degree = $\frac{5}{9}$ C. degree. When the *reading* of one scale is to be transformed into the equivalent *reading* on the other, the differing positions of the zero point must be considered. These formulas may be used:

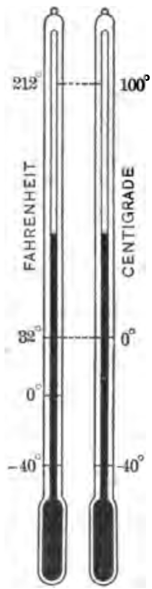


FIG. 224

$$C = \tfrac{5}{9}\,(F - 32°) \qquad (45)$$

$$F = \tfrac{9}{5}\,C + 32° \qquad (46)$$

or

$$\frac{C}{100} = \frac{F - 32}{180}. \qquad (47)$$

Another formula is based upon the fact that $-40°$ indicates the same temperature on both scales. Hence to change a F. reading to a C. reading, add 40° to the F. reading, multiply the sum by $\frac{5}{9}$, and subtract 40° from the product:

$C = \frac{5}{9}\,(F + 40) - 40 \qquad F = \frac{9}{5}\,(C + 40) - 40$

252. Limitations of Mercury Thermometers.—The glass bulb of a thermometer may gradually change in volume. There may also be a temporary change after use for high temperatures in which the bulb returns slowly to its original volume. A thermometer, therefore, should be frequently tested to determine what correction is necessary in reading.

For very low temperatures alcohol is used instead of mercury, which freezes at $-39°$ C. The ordinary form of mercury thermometer cannot be used for temperatures above 350° C., since its boiling point is 357° C. When the space above the mercury column, however, is filled with nitrogen under pres-

sure, it can be used for temperatures up to 550° C. For still higher temperatures the air thermometer or the electric pyrometer is used.

253. The Air Thermometer. — A simple *air thermometer* (Fig. 225) can be made by thrusting the tube of an air thermometer bulb through a rubber stopper with two holes, and fitting this stopper to a test tube or bottle nearly full of colored water. A scale along the side is used for reading the height of the water column, which is introduced by driving out a few bubbles of air from the bulb by heating it. When the air cools, the water will rise in the stem (Fig. 225). The position of the water column is affected by the varying pressure of the air as well as by the temperature, so that it will not correspond directly with the readings of the mercurial thermometer.

FIG. 225

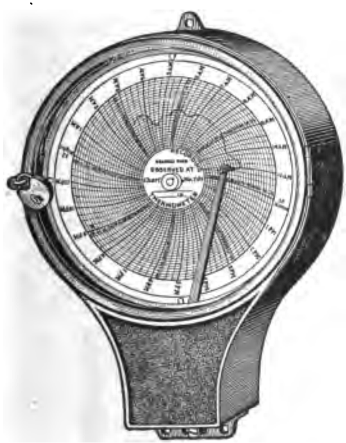


FIG. 226

254. Metallic Thermometers.—A compound *bar* made by riveting together two thin strips of brass and iron will, when heated, form an arc of a circle, with the brass on the outside. This unequal expansion of two metals is the regulating principle in the *metallic thermometer*. A convenient form is made by fastening the two metals together in the form of a spiral spring, having on the outside the one with the greater rate of ex-

pansion. One end of the spring is fixed, and the other end acts upon a pointer which marks off the temperature on a scale on the face of the instrument. Figure 226 shows a self-recording thermometer of this type. The time card is rotated once per day by clockwork, while the record is made by a pen at the end of the pointer.

255. The Clinical Thermometer is used in taking the temperature of the human body. The tube of this thermometer is pinched nearly together near the lower end. When the thermometer cools, the mercury column breaks at this narrowest part, and the column in the tube remains

FIG. 227. — Clinical Thermometer

just as it was at the highest temperature during the time of its use; the reading, therefore, can be taken at any time. Before it is used again, the column is reduced by a jerking motion which forces some of the mercury past the constriction into the bulb.

256. Maximum and Minimum Thermometers are used by the stations of the Weather Bureau to show the highest and lowest temperatures during each day. One form of

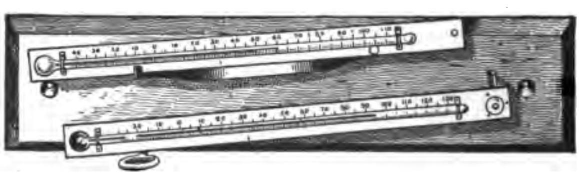


FIG. 228. — Minimum and Maximum Thermometers

maximum instrument is made like the clinical thermometer. After being read it is set by swinging it around in a circle,

so that the centrifugal force drives the mercury back into the bulb, and the instrument is then ready for the next day. One form of minimum thermometer is an alcohol thermometer with a small glass spool or index moving loosely in the tube. This is drawn down by surface tension whenever the end of the liquid column touches the end of the spool as the liquid contracts; but when it expands, the liquid runs past the spool and leaves it at the point of lowest temperature. To set this thermometer it is merely necessary to tip the tube slightly, and the spool will run to the end of the liquid column and stop.

Questions

1. Suppose a basin (A) to be partly filled with ice water, another (B) with tepid water, and a third (C) with warm water. If the left hand is thrust into A, the right hand into C, and after a time both are thrust into B, how will the water in B feel to the left hand and how to the right hand? What does this teach?

2. What is the difference between quantity of heat and temperature?

3. Why is one end of a railroad bridge sometimes placed upon small rollers?

4. Which expands more with a rise of temperature, the glass bulb of a thermometer or the mercury that it contains? What proof have you?

5. Why is a wagon tire put on when hot?

6. What would be the effect of placing a football on a warm radiator?

7. What is the reading of the *fixed points* of a thermometer? Why are they called fixed points?

8. What is assumed when the length of a thermometer stem between 0° and 100° is divided into 100 equal parts?

9. Suppose that a compound bar is made of two metals, A on the right and B on the left. If A expands more than B, which will be on the outside of the curved bar when the temperature rises?

10. Why does the mercury column in a clinical thermometer break when it cools after being used?

11. Suppose you wish to take a temperature quickly. Would you use a thermometer with a large or a small bulb? Why?

12. Suppose you need to observe very slight changes of temperature. Would you use a thermometer with a large or a small bore? Why?

Problems

1. What change in Fahrenheit degrees corresponds to a change of 25 Centigrade degrees?

2. If the change in Fahrenheit degrees is 27, what is the equivalent change in Centigrade degrees?

3. What Fahrenheit reading corresponds to the reading 25° C.?

4. What Centigrade reading corresponds to the reading 27° F.?

5. For what temperature do the Centigrade and Fahrenheit thermometers give the same reading?

6. The normal temperature of the body is 98.4° F. What is it in the Centigrade scale?

7. Seventy-six degrees is called Summer Temperature on a Fahrenheit thermometer. What will be its reading on a Centigrade thermometer?

8. The boiling point of liquid air is – 192.2° C. What is this temperature on the Fahrenheit scale?

9. The melting point of iron is 1520° C. What Fahrenheit reading indicates the same temperature?

10. The temperature of a room changed 17 Fahrenheit degrees. What was the change in Centigrade degrees?

II. PRODUCTION AND TRANSMISSION OF HEAT

257. Sources of Heat. — The principal sources of heat are the *sun; the interior of the earth; mechanical sources* such as *friction, impact,* and *compression,* in which work is changed into heat; *chemical action,* in which chemical energy is transformed into heat; and the heat caused by the passage of an *electric current.*

That the sun is a source of heat needs no proof, while the experience of miners working in deep mines proves that there is internal heat, the temperature rising as the distance from the surface increases.

258. Friction. — There are many familiar examples of the heating effects of friction. The train of sparks that fly from a sleigh runner as it passes over a stone, and the sparks that come from a car wheel when the brake is applied, both show that great heat is generated by the friction; for the sparks are burning iron. The hands are warmed by rubbing. A match is set on fire by friction, and a piece of wood in a turning lathe is charred when the corner of another piece is held against it.

259. Impact. — When two bodies meet in collision, the effect of the blow is to increase the rate of vibration of the molecules, and hence to raise the temperature of the bodies. An example of this is seen in the fact that one end of an iron bar can be heated by placing it on an anvil and striking it several vigorous blows.

260. Compression. — When a gas is suddenly compressed there is a corresponding sudden rise in its temperature. In steam air compressors of the double cylinder type, the heated air coming from the first compressor cylinder is cooled before going into the second by being passed through pipes surrounded by cold water.

261. Chemical Action. — Many chemical combinations give rise to heat. The most familiar of these is the combination of oxygen with carbon, as seen in combustion; for example, the burning of a match or of coal. If 1 c.c. of concentrated sulphuric acid is poured into 4 c.c. of water in a test

tube, both liquids being at the room temperature, it will be found that the mixture is several degrees hotter. *Animal heat* is due to oxidation within the body.

262. The Transmission of Heat. — When two bodies are brought in contact with each other, each communicates a part of its molecular energy, or heat, to the other. If the two bodies are of the same temperature, each receives as much as it imparts, and there is no change in the temperature of either. If, however, the body *A* is of a higher temperature than the body *B*, it gives more heat than it receives, and its temperature is lowered by an amount which depends upon the difference between the two temperatures; while the body *B* has its temperature raised, and we say heat has been transmitted to it. Heat can be transmitted in three ways — by *conduction*, by *convection*, and by *radiation.*

263. Conduction; Conductivity of Solids. — If one end of a copper wire 10 cm. long is held in the hand and the other end is placed in the flame of a Bunsen burner, the end in the flame will become red-hot, and in a short time the end in the hand will become uncomfortably warm. This method of transmission, by which the heat is transferred from molecule to molecule along the body, is called *conduction.* If the same experiment is made with a glass tube, the glass can be melted to within 4 or 5 cm. of the fingers without burning them, while a stick can be burned to the very fingers without harm.

These three examples illustrate bodies that are *good, medium,* and *poor* conductors of heat. A good conductor feels either warmer or colder than a poor conductor if not at the same temperature as that of the hand. This is due to the fact that it conveys its heat to the hand, or takes heat from the hand, more readily than the poor conductor.

TABLE OF RELATIVE CONDUCTIVITIES

Silver	1000	Lead	85
Copper	736	Platinum	63
Brass	235	German silver	60
Tin	145	Glass	20
Iron	119	Wood lengthwise of the grain	3

264. The Davy Safety Lamp. — It frequently happens that an explosive mixture of gases accumulates in some part of a mine. An ordinary lamp brought in contact with this mixture would cause an explosion. To prevent this, and still make it possible to use a light, Sir Humphry Davy devised a form of lamp in which, as the illustration shows, the flame is entirely surrounded with wire gauze. Whenever the lamp is brought into an inflammable mixture of gases, some of the mixed gas will enter the lamp and burn there. But so great is the heat conductivity of the gauze that the gas outside the lamp does not receive heat enough to take fire until the gauze becomes red hot.

FIG. 229. — Davy Lamp

An experiment that shows this conductivity can be made by placing a piece of wire gauze upon a tripod with a Bunsen burner beneath it. The gas may be lighted either above or below the gauze, and the flame will not pass through (Fig. 230).

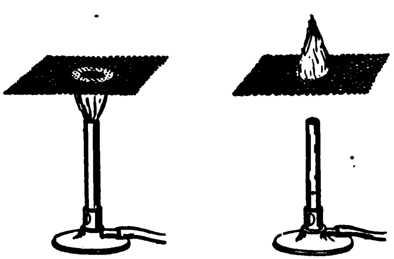


FIG. 230

265. Conductivity of Liquids. — Liquids as a class are poor conductors

of heat, the conductivity of water being about $\frac{1}{800}$ of that of copper.

Demonstration. — Put some pieces of ice in the bottom of a test tube. Fasten them there with a coil of wire. Pour in water until the tube is nearly full, and then hold it over a Bunsen burner so that the heat will be applied at a point covered by the water. In this way the water in the upper part of the tube may be boiled while there is ice in the bottom only a few centimeters away.

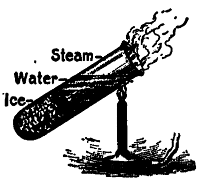


FIG. 231

266. Conductivity of Gases. — Gases are extremely poor conductors of heat, the conductivity of air being only $\frac{1}{2000}$ of that of copper. Double windows prevent air currents that would carry away the heat, and on account of the low conductivity of air are a protection from the cold.

The fur of animals is an efficient protection because of the layer of air that is connected with it. The protection in both these cases consists in preventing the heat from within from escaping. Practical use of air spaces to prevent the transfer of heat is made in the double walls of ice houses and refrigerators, for keeping the heat out, and in fireless cookers for keeping the heat in.


FIG. 232.—Thermos Bottle

Still better results are obtained by exhausting the air from between the double walls, as in the thermos bottle, in which either hot or cold liquids can be kept without much change of temperature for some hours.

267. Convection. — If a part of a fluid body (liquid or gas) is heated, it expands (§ 245) and becomes lighter, bulk for bulk, than the other parts. As the molecules are free to move, the cooler, heavier parts tend to sink to the bottom, and thus to push the warmer parts to the top. There is thus set up an ascending current wherever any part of the liquid or gas at the bottom is heated above the rest; and downward and lateral currents in the cooler parts. All these currents are called *convection currents.*


FIG. 233

Demonstration. — Fit a rubber stopper with two holes to the mouth of a thin glass flask. Through these holes thrust two glass tubes about 8 cm. long, making an end of one nearly even with the top of the stopper, and an end of the other nearly even with the bottom. Fill the flask with colored water and heat it. Put in the stopper and sink the flask in a large glass of cold water, as in Fig. 233. Convection currents will be set up by the warm water coming out of one tube while the cold water goes into the other. Into which will the cold water go? Why?

268. Heating Buildings with Hot Water. — The hot water system has become a very common method of heating buildings. It works by means of the convection currents that are set up in a system of water pipes when a section near the bottom is heated more than the rest. A miniature heating system can be set up and put in operation by the use of the apparatus shown in Fig. 234. By coloring part of the water the paths of the convection currents can be readily traced. The heating of a house is only an extension of this experiment.

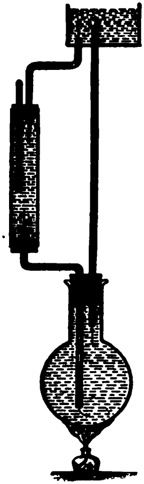


FIG. 234

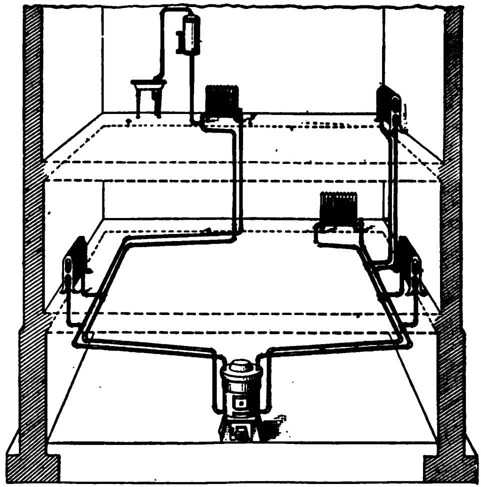


FIG. 235. — Hot Water Heating System

In the hot water system shown in Fig. 235, the hot water leaves the heater by the upper pipes, goes through the different radiators, and then back to the heater, which it enters at the bottom. In this system the pipes must be kept filled with water. The height of water is read from a gauge attached to the tank, which is higher than any of the radiators.

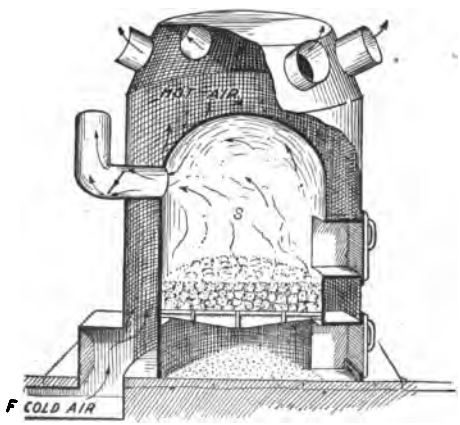


FIG. 236. — Diagram of a Hot Air Furnace

269. Convection in Gases. — Air that is in contact with a heated surface be-

comes itself heated, and convection currents are set up in the same way as in liquids. This can be shown by lighting a piece of touch-paper and holding it over a piece of heated metal, when the smoke will rise with the current of air.

Convection currents in air are made use of in warm air systems of heating. Cold air enters the heater at the base, and after being heated, passes out through the warm air delivery tubes, which distribute it throughout the building.

NOTE. — Touch-paper is made by dipping filter paper or blotting paper into a solution of saltpeter. When dry it will burn without flame, but will give off smoke freely.

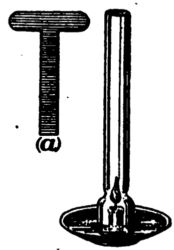


FIG. 237

Demonstration. — Set a short piece of candle in a saucer and light it. Set over it a chimney from a student lamp. Pour water into the saucer to prevent air going into the chimney from the bottom, and the candle will soon go out. Why? Cut a piece of tin of the shape shown in (*a*) in Fig. 237, and put it down the chimney with the wide part resting on the top. Light the candle again, and it will keep on burning. Why? Examine the air on both sides of the tin, by the smoke from touch-paper.

270. Ventilation. — The preceding demonstration shows the need of renewing the air in order to support combustion. It also shows that this renewal is secured by means of convection currents. A room is ventilated, more or less, by convection currents through chimneys, windows, and crevices in floor and walls, whenever the temperature in the room differs from that outside.

In a house that is heated by a hot-air furnace, good ventilation is secured by bringing the air to be heated from outside the house. The distribution of the heated air takes place in convection currents. The difficulty with this method of heating is that it is

affected by the direction of the wind, the hot air going most freely into the rooms situated on the opposite side of the house from the direction of the wind; into the south rooms if the wind is from the north, for instance. Figure 238 shows how fresh air can be secured when hot water or steam heating is used.

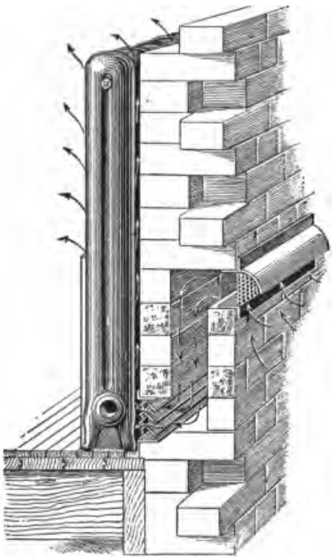


FIG. 238

271. Radiation of Heat. — The third method by which heat may be transferred from one body to another is by *radiation.* If the open hand is held in front of a stove, the radiant energy sent out by the fire is received on the hand and it becomes warm, though the air may not feel warm. If a screen is placed between the stove and the hand, the radiation is cut off. The earth receives heat from the sun in the form of radiant energy. This radiant energy is defined as a wave motion in the *ether* which is supposed to fill all space. When the vibrations of the ether are received by a body, they set its molecules into more rapid vibration, which raises its temperature, increasing its heat.

272. Nature of the Ether.—The all-pervading ether must be elastic and rigid, and capable of displacement and of exerting pressure. It may be considered as a universal jelly, so thin as to pass readily through every known substance, and to permit the densest substance to pass through it as a sieve passes through the air; a jelly so thin that it

has no appreciable weight and has caused no measurable change in the velocity of any heavenly body.

273. Laws of the Radiation of Heat.

I. *Radiation takes place through a vacuum as well as in the air.* This results from the nature of the radiation, for the medium by means of which the radiation takes place is the ether and not the air. If this law were not true, we should receive no heat from the sun and but little from the bulb of an incandescent lamp.

II. *Radiation in a vacuum or in a homogeneous substance takes place in straight lines.* A *homogeneous* substance is one that has the same physical structure throughout.

III. *The intensity of radiant heat is proportional to the temperature of the source.*

IV. *The intensity is inversely proportional to the square of the distance from the source.* The proof of this law is like that in § 214, *c*.

Fig. 239. — Radiometer

274. The Radiometer is an instrument used to detect radiant heat. It consists of a glass bulb inclosing two arms of aluminum crossing each other at right angles and carrying at each end a mica vane, one side of which is coated with lampblack while the other is bright. These arms are fastened horizontally to a vertical shaft which can rotate with them. The air is nearly exhausted from the bulb. When these vanes are subjected to the action of radiant heat, they set up a rotation, the velocity of which is dependent upon the intensity of the heat received.

This is due to the fact that the molecules of rarefied air in their vibration (§ 243) bound back and forth between the vanes and the walls of the bulb; that the blackened side of each vane becomes warmer than the other; and that the molecules rebound from the warmer side with greater speed, producing a greater reaction of pressure on that side.

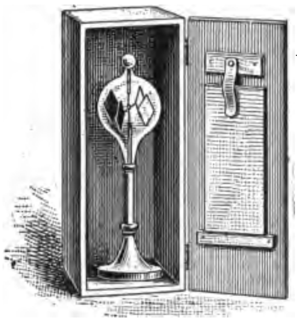


FIG. 240

Demonstration. — Make a light-tight box, large enough to hold a radiometer. Heat a flat piece of cast iron or brass nearly to a red heat and fasten it to the inner face of the door of the box (Fig. 240). Put the radiometer into the box and close the door. Leave it closed for about a minute and on opening it the radiometer will be found to be rotating. Is it heat or light that produces the rotation?

275. The Reflection of Radiant Heat. — Experiment proves that radiant heat is reflected in accordance with the following laws (compare with § 65):

I. *The incident and reflected rays are in a plane that is perpendicular to the reflecting surface.*

II. *The angle of reflection is equal to the angle of incidence.*

Demonstration. — Place two concave mirrors directly opposite each other, as at M and M' (Fig. 241). In the focus of M place the

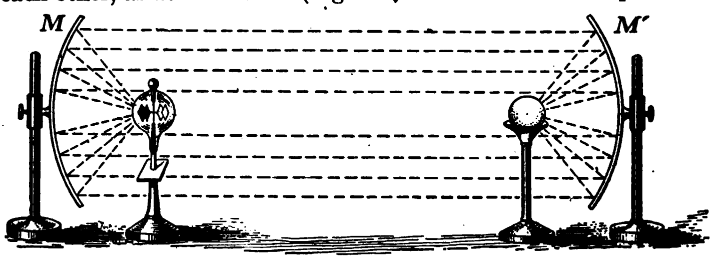


FIG. 241

radiometer and in the focus of M' place an iron ball heated nearly to redness. Have the mirrors far enough apart so there will be no rotation due to direct radiation from the ball. When the ball and the radiometer are in the foci of their respective mirrors, the radiometer will set up a brisk rotation due to reflected radiation.

276. Radiating and Absorbing Powers. — The radiating power of a heated body depends upon its temperature and the character of its surface. A body with a smooth, brightly polished surface has a much lower radiating power than one of the same material but with a dull surface. Bodies that absorb heat readily are good radiators and poor reflectors. The power of absorption depends somewhat upon color. This can be shown by placing upon snow two pieces of cloth, one black and the other white. It will be found that when the sun shines upon them, the black piece will absorb heat and melt its way into the snow, while the white will not.

277. Selective Absorption. — The extent of the absorption depends, in some substances, upon the temperature of the source of heat.

Demonstration. — Set a radiometer in front of a fishtail gas flame so near that it will rotate briskly. Place a pane of glass between them. Much of the radiation will be absorbed by the glass, some will be reflected, and the rotation will nearly stop. Set the radiometer in the sunshine. After it is in motion hold the glass plate between it and the sun. Does the rotation stop?

The fact that glass permits much of the radiation from the sun to pass through, but does not permit the passage of radiation from bodies of much lower temperature, is of great importance, since radiation from the sun enters our rooms through the windows and heats them, while the radiant heat from stoves and radiators cannot pass out.

The radiant heat that comes from the sun and passes

through the glass readily is called *luminous heat*, because it comes from a source that also gives light. Radiant heat that comes from bodies of comparatively low temperature and is largely absorbed by the glass is called *nonluminous heat*.

Substances like rock salt, which permit radiant heat to pass through them readily, are called *diathermanous*, while those like glass and water, that absorb radiant heat, are called *athermanous*.

Demonstration. — Place a flat battery jar between a radiometer and the sun. Does the rate of rotation change? Fill the jar with water. Is there any greater change?

Questions

1. How do you explain the fact that a meteor becomes luminous when it strikes our atmosphere?

2. Why are the chips that are turned from an iron rod hot?

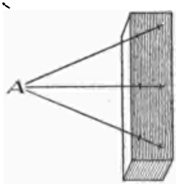


FIG. 242

3. Why is a rifle cartridge exploded when the hammer falls?

4. Why does a bicycle pump become warm when used to pump air into a tire? Give two reasons.

5. If three wires, one of copper, one of iron, and one of German silver, are fastened on a block, the projecting ends covered with paraffin, and thrust into a Bunsen flame at *A*, the paraffin will melt at different rates. Why? If it melts 6 inches on the copper wire, how far will it melt on each of the other two?

6. Why is a flatiron handle made of wood rather than of iron?

7. To cool some hot water by setting it in a cold room, would you put it in a tin pail or in a wooden pail? Why?

8. Describe the result of the selective absorption of the glass roof of a hothouse upon the temperature within it.

9. When an arc-light lantern is used to project a microscope slide, why is a water cell put between the arc light and the slide?

10. Make a diagram of walls suitable for an ice house.

11. Why does a dead leaf resting on the snow sink into it on a sunshiny day?

12. Why does a piece of flannel lying on a marble table top feel warm while the marble itself feels cold?

13. What is best for a steam or hot water radiator, a highly polished or a dull surface?

14. Why is it that a thermos bottle will keep a liquid either hot or cold?

III. EXPANSION, FUSION, AND VAPORIZATION

278. The Measurement of Expansion of Solids. — The first demonstration in § 245 proves that when the temperature of a solid increases, the solid expands; but that demonstration gives no definite idea of the amount of this expansion. The amount of expansion varies with different substances, but for a given solid it is directly proportional to the temperature.

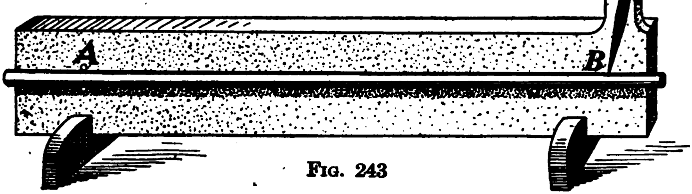


FIG. 243

Demonstration. — Set up the apparatus shown in Fig. 243, in which the copper tube AB is fixed to the support at the point A, and note both the temperature of the room and the reading of the pointer. Cover the copper tube with a non-conductor, attach a rubber tube to either end, and send steam through it from a boiler.

After the steam has been coming through the tube freely for some time, take a second reading of the pointer and call the temperature of the steam 100° C.

From the above readings the changes in length of the tube and the changes in its temperature can be found. Then we can write the following:

$$\frac{\text{The change in length of } AB}{\text{The change in temperature}} = \text{The change in length for 1}$$
degree.

$$\frac{\text{The change in length for 1 degree}}{\text{The original length of } AB} = \textit{The expansion of unit}$$
length for 1 *degree,* and this is *the coefficient of linear expansion.*

In general: The new length = The original length + The increase in length, or $L' = L + ktL$,

$$\text{or} \qquad L' = L(1 + kt), \tag{48}$$

in which L is the length of the rod at zero, L' is its length at the temperature $t°$, and k is the coefficient of linear expansion.

TABLE OF COEFFICIENTS OF LINEAR EXPANSION

Invar[1]	0.00000087	Railroad Steel	0.00001320
Pine	0.00000608	Copper	0.00001718
White Glass	0.00000861	Brass	0.00001878
Platinum	0.00000884	Aluminum	0.00002313
Cast Iron	0.00001125	Ice	0.00006400

279. Effects of Expansion in Solids. — The difference in temperature between the coldest winter days and the hottest days of summer is enough to make a perceptible change in the length of long pieces of metal. Telephone and telegraph wires sag more in summer than in winter. Suspension bridges, like the Brooklyn Bridge, are several inches higher in the middle in midwinter than in summer. Bridge work and steam boilers are put together with red-hot bolts, so that the parts may be more firmly held together when the bolts are cool.

The table shows that the coefficients of expansion of glass and platinum are nearly the same. It is for this reason,

[1] A nickel-steel alloy containing 36% of nickel.

and because platinum does not oxidize, that this metal is used as the sealed-in wire in incandescent lamps. A substitute for platinum for this purpose can be made by using a compound wire, the core of which is a nickel-steel alloy, over which is a thin sheathing of copper. This compound wire has a coefficient of expansion slightly less than that of platinum. As it is less expensive, it is generally used in place of platinum.

A thermostat is an example of the application of the unequal expansion of metals (Fig. 244). A compound bar of copper and iron is fixed at one end and free to move at the other. When the temperature rises the point P completes the circuit through the cell C and the bell B. When the temperature falls the circuit is made through B'. By choosing bells of a different tone it is easy to tell whether a room, a greenhouse for example, is too hot or too cold. If electromagnets are substituted for the bells, they can be made to open and close the door that controls the draft of a furnace, so that the device automatically regulates the temperature.

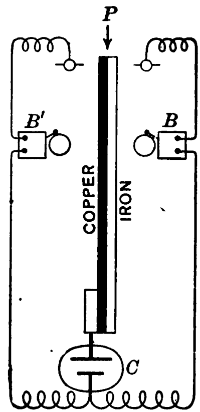


FIG. 244

280. Cubical Expansion. — When a solid body expands, it expands in all directions. If the form of the body is a cube and the length of each edge at zero temperature is 1, the length after expansion will be $L' = 1 + Kt$. The volume at $t°$ will be $(1 + Kt)^3 = 1 + 3\ Kt + 3\ K^2t^2 + K^3t^3$. Since K is an extremely small fraction, as is seen from the table, the second and third powers of K are fractions so small that the terms $3\ K^2t^2$ and K^3t^3 can be neglected, and the vol-

ume is considered equal to $1 + 3\,Kt$. Hence the *coefficient of cubical expansion*, or the fraction of its volume at zero temperature that a body expands on being heated 1° C., is considered to be three times the coefficient of linear expansion.

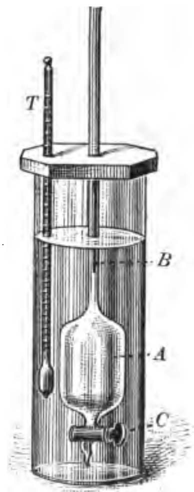


FIG. 245

The coefficient of cubical expansion of ice is 0.000192; compare this with its linear expansion.

281. The Expansion of Water. — Demonstration. — Fill the bulb A, Fig. 245, with water at 4° C., up to the zero mark on B, at which point the volume of the bulb is 100 c.c. Close C and warm the water in the beaker to the temperature t° C.

Both the glass and the water expand, but the expansion of the water being much greater than the expansion of the glass, it rises in the calibrated tube. The amount of the expansion at t° in cubic centimeters, divided by the product of 100 c.c. $\times (t - 4)$ will give the average apparent expansion of water in glass per degree for the range of temperature tested.

The temperature 4° is taken as a basis in the determination of the apparent expansion of water, because at that temperature water has its smallest volume and *maximum density*. The liquid water expands not only when its temperature is raised above 4°, but also when its temperature is lowered below 4°. In the latter, which is known as its *anomalous expansion*, water differs from other liquids. When winter approaches, the water of ponds and lakes becomes colder at the surface and sinks, setting up convection currents, so that, before the water at the surface becomes colder than 4°, the entire body of water is of the uniform temperature of 4°. Were it not for the anomalous expansion of water, this process

would continue down to the freezing point. This expansion, however, stops the convection currents, and when freezing begins, the water quite near the top is the only part that is colder than 4°, hence fish that are under the ice are in water of an almost uniform temperature.

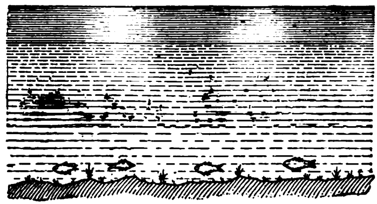


FIG. 246

Since the change in volume per degree is very small, it is best shown by a curve in which the scale of volumes is taken very large. In Fig. 247 each division in the vertical scale represents 0.00005 of the volume at 4°.

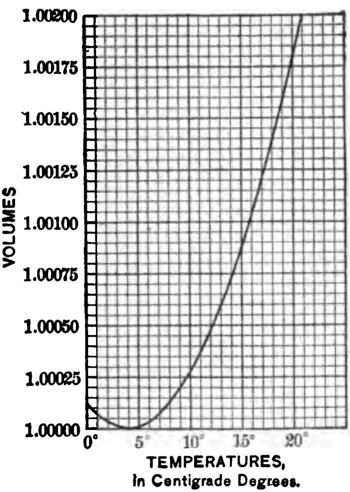


FIG. 247. — Expansion of Water

The expansion of water is not uniformly proportional to the temperature. As we go from 4° in either direction, the amount of expansion per degree constantly increases. From 4° to 5° the expansion is 0.000008 of the volume at 4°; from 14° to 15°, 0.000146; from 24° to 25°, 0.000253. Liquids in general have different rates of expansion at different temperatures; in this they differ from solids and gases, which expand uniformly.

The rate of expansion of mercury, however, is nearly uniform. Its coefficient of cubical expansion, for temperatures near zero, is 0.0001818.

282. The Measurement of Expansion of Gases. — The varying volume of the air in an air thermometer shows that a gas expands when heated, but it does not show the amount of the change in volume per degree. There are two conditions under which the effect of heat on a gas can be measured. If the gas is heated and the pressure kept constant, we can measure the change in its volume; and if the gas is heated and the volume kept constant, we can measure the change in its pressure.

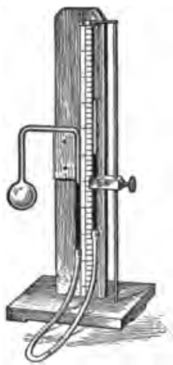


Fig. 248

Measurements under both these conditions can be made by the use of an air thermometer such as is shown in Fig. 248. In measurements under constant volume the mercury in the left-hand column is kept at a fixed height by raising or lowering the right-hand column, and in measurements under constant pressure the mercury level is kept at the same height in both columns by the same means.

As a result of such measurements it is found that for each degree of change in the temperature of a gas under constant pressure there is a change in its volume equal to $\frac{1}{273}$ of its volume at zero. Since this is true of all other gases as well as of air, we can write $\frac{1}{273}$ or 0.003665 as the uniform coefficient of expansion of all gases.

283. Absolute Zero. — If a given mass of gas with a volume of 273 c.c. at zero is steadily cooled, its volume will be 263 c.c at − 10°, 253 c.c. at − 20°, and so on. The logical conclusion would be that if the temperature were reduced to − 273° the volume of the gas would be zero. Before reaching that temperature, however, gases change into liquids. The temperature − 273° is called the *absolute zero*,

and temperatures based upon this temperature as 0° are called *absolute temperatures* and expressed as degrees Kelvin. Thus 20° C. = 293° K. Gases are liquefied by increasing the pressure and reducing the temperature, and by the evaporation of liquid helium under reduced pressure the temperature has been brought as low as − 270°.

284. The Law of Charles. — The discovery that all gases are subject to the same law governing the relation of volume and temperature at constant pressure, was made by Professor Charles of Paris. The law which has received his name may be stated as follows:

Under a constant pressure the volume of a given mass of gas is proportional to its absolute temperature.

285. Combination of Boyle's Law with the Law of Charles.

Let V = the volume and P the pressure of a gas at $t°$.
Let V' = its volume and P' its pressure at $t'°$.
Let V_1 = its volume at the pressure P' and temperature $t°$.

Then by Boyle's law $PV = P'V_1$, since the temperature is $t°$.

By the law of Charles $\frac{V_1}{T} = \frac{V'}{T'}$ since the pressure is P', T and T' being absolute temperatures corresponding to $t°$ and $t'°$ respectively.

Multiplying these equations term by term we get, by eliminating V_1,

$$\frac{PV}{T} = \frac{P'V'}{T'}. \tag{49}$$

This formula is used in the solution of such questions as the following:

Example. — The volume of a gas at 22° C. and 760 mm. pressure is 50 c.c. What will it be when the temperature is raised to 100° C.

and the pressure is 700 mm.? Since T is the absolute temperature, substitution in the formula gives

$$\frac{760 \times 50}{273 + 22} = \frac{700 \times V'}{273 + 100},$$

whence $$V' = 68.8 \text{ c.c.}$$

286. Effects of Expansion in the Air. — The effect of heat upon air may be seen in the currents that are set up near a heated surface. The air next the surface becomes warmer and lighter, and cooler air displaces it. This sets up an ascending current over the heated area, and a horizontal current at near-by places. If this heated surface is an extensive tract of the earth, the result will be the setting up of violent winds toward it.

Just as the temperature of air is raised by compression (§ 260), so also it is lowered by expansion against reduced pressure. The ascending current over the heated surface rises to an altitude where the atmospheric pressure is considerably less. Because of the resulting expansion of this air, the temperature is likely to fall so low as to cause the condensation of its water vapor into clouds and rain.

The beginning of a thunderstorm exemplifies both these effects. Use is made of the second effect in liquefying air and other gases. The pressure on highly compressed cold air is suddenly reduced, and the resulting expansion of part of the air withdraws so much heat from the rest that the residue is liquefied.

287. Changes of Physical Condition. — If, when the temperature is several degrees below zero, a piece of ice is brought into a warm room, its temperature rises until it is at zero. If now more heat is applied to it, it melts to a liquid, then heats to 100°, and then boils away. In the course of this process there has been one change of the body from a solid

to a liquid, and another from a liquid to a vapor. A similar change of physical condition can be brought about with most solid bodies if only the proper change of temperature can be produced.

288. Fusion. — Demonstration. — Draw out a piece of glass tubing until its inner diameter is 1 mm. cr less, and close the end. Drop into the open end a small piece of beeswax and hold the tube in a flame until the wax is melted. Let it solidify at the closed end. Tie the tube to a thermometer as shown in Fig. 249. Put the thermometer and tube into a beaker of water and heat it until the wax melts. Take the temperature of melting, remove the source of heat, and again read the thermometer at the instant that the wax begins to solidify. Take the mean of the two readings as the melting point of the wax.

FIG. 249

The change from a solid to a liquid as a result of the application of heat is called *fusion*, or melting. The temperature at which a solid melts is called its *melting point.* The *laws of fusion* are as follows:

I. *Every solid having a crystalline structure begins to melt at a certain fixed temperature that is always the same for that substance if the pressure is constant.*

II. *The temperature of a melting solid remains unchanged from the time melting begins until the body is entirely melted.*

TABLE OF AVERAGE MELTING POINTS

Alcohol	−130.50°	Lead	326°
Mercury	− 39.04°	Silver	950°
Ice	0°	Copper	1100°
White wax	65°	Iron	1500°
Sulphur	115.1°	Platinum	1900°

289. Solidification is the reverse of fusion, and takes place when a liquid is cooled below its melting point. The temperature at which any substance solidifies is the same as the melting point, and for some substances, as water and mercury, this temperature is called the *freezing point.* Every liquid in freezing gives off an amount of heat equal to that which would be required to melt it if frozen. The freezing point of vegetables is a little lower than the freezing point of water. For this reason pans of water are sometimes placed in vegetable cellars, in order that the water, while freezing, may give out heat enough to keep the air above the freezing point of the vegetables.

Most liquids shrink on solidifying; but water, on the contrary, expands. Water expands so that 917 c.c. of water becomes 1000 c.c. of ice. Were it to decrease in volume instead, the crystals of ice forming at the surface of a lake would sink, and during a cold winter the water would become solid ice from the bottom to the top.

Demonstration. — Fill with water an air thermometer bulb with a long stem, and pack the bulb in a freezing mixture. The water in the stem will be seen gradually to sink, then to turn and rise, indicating that the minimum volume has been passed, and then suddenly to rise again. On taking the bulb out after some minutes it will be found broken, and the water will be a ball of ice.

290. Effect of Pressure on the Freezing Point. — The effect of increased pressure on the freezing point of water is seen in the following:

Demonstration. — Place a block of ice on a suitable support and put over it a piece of wire with a heavy weight at each end. This brings pressure upon the ice directly under the wire and it will melt. As the wire sinks in the ice the melted water above it,

being freed from pressure, freezes again and finally the wire will cut entirely through the ice, which will still remain as a single block.

This thawing and freezing of ice under great changes of pressure is seen in a large scale in glaciers, their constant flow down a slope being dependent on this action.

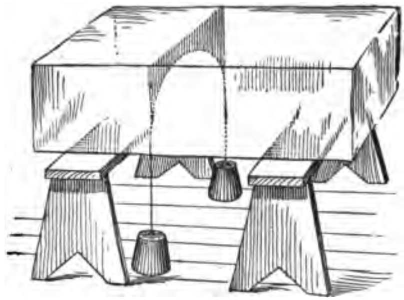


FIG. 250

291. A Freezing Mixture can be made by mixing 1 part of salt with 3 parts of snow or cracked ice. The ice in contact with the salt is melted, the heat necessary for the melting being withdrawn from the objects near by. The salt is dissolved, and the temperature falls to the freezing point of the salt solution, which is lower than that of water. Other salts mixed with ice or snow will give lower temperatures, as calcium chloride, for example. When this salt is mixed with snow in the proportion of 3 parts of the salt to 2 parts of snow, it will give a temperature low enough to freeze mercury.

292. Vaporization. — As the molecules of water (or ice) in their vibration (§ 243) strike against the surface, many of them force their way through it and pass into the air, where they exist as molecules of water vapor. When heat is applied, the temperature is raised, which means that the velocity of the molecules is increased; and the number of molecules that pass into the air increases with their velocity. As long as the temperature is below the boiling point, the process is called *evaporation*.

293. Laws of Evaporation.

I. *Evaporation increases with the temperature.* Evaporation takes place even at very low temperatures. A block of ice left for a few days in a place where the temperature is below zero will lose a considerable amount by evaporation. Wet clothes hung out on a cold winter day will freeze at once, but will soon become dry.

II. *Evaporation increases if the surface of the liquid is increased.* Recent experiments show that evaporation is not directly proportional to the extent of the surface. Evaporation takes place more rapidly near the boundaries of a surface than at the center, and in the case of two circular surfaces the evaporation is nearly proportional to the respective circumferences.

III. *Evaporation is inversely proportional to the pressure upon the liquid.*

IV. *Evaporation decreases as the air becomes saturated.*

Air is said to be *saturated* with moisture when it will hold no more at the given temperature. If the temperature is raised, more evaporation can take place, but if it is lowered, *condensation* will take place; that is, some of the vapor will be changed back to tiny water drops or ice crystals. At any given temperature the amount of vapor necessary for saturation is always the same per cubic meter of space, no matter how much air is also in that space.

If the space into which evaporation takes place is inclosed and the air is removed, the evaporation takes place rapidly, and saturation is quickly reached. If the air is not removed, the evaporation takes place much more slowly, because the air molecules, striking upon the surface of the water, cause a pressure upon the surface and oppose the molecules that

NUMBER OF GRAMS OF MOISTURE NEEDED FOR SATURATION PER CUBIC METER AT VARIOUS TEMPERATURES C.

− 10°	2.363 g.	5°	6.761 g.	20°	17.118 g.
− 9°	2.546	6°	7.219	21°	18.143
− 8°	2.741	7°	7.703	22°	19.222
− 7°	2.949	8°	8.215	23°	20.355
− 6°	3.171	9°	8.757	24°	21.546
− 5°	3.407	10°	9.330	25°	22.796
− 4°	3.659	11°	9.935	26°	24.109
− 3°	3.926	12°	10.574	27°	25.487
− 2°	4.211	13°	11.249	28°	26.933
− 1°	4.513	14°	11.961	29°	28.450
0°	4.835	15°	12.712	30°	30.039
1°	5.176	16°	13.505	31°	31.704
2°	5.538	17°	14.339	32°	33.449
3°	5.922	18°	15.218	33°	35.275
4°	6.330	19°	16.144	34°	37.187

are coming from the liquid. In the first case the final pressure is that of the saturated vapor alone. In the second case it is that of the air plus that of the saturated vapor. The effect of atmospheric pressure upon the rate of evaporation is so great that the moisture present in the air is generally much less than that required for saturation.

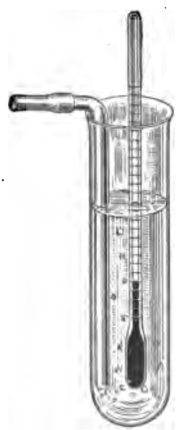


FIG. 251

294. The Dew-point. — **Demonstration.** — Pour ether into a test tube until it is half full, and put a thermometer into it. Bend a tube at right angles and place in the test tube as in Fig. 251. Connect the short end with a long rubber tube and blow gently through the ether. The ether will evaporate and the temperature will rapidly fall. Watch the surface of the lower end

of the test tube and take the reading of the thermometer when moisture first appears on the outside. Now stop blowing through the ether, and its temperature will rise. Take a second reading of the thermometer when the moisture disappears. The average of the two readings will be the *dew-point.*

The dew-point is the temperature to which air must be lowered so that the vapor present will be enough for saturation.

Fogs, clouds, rain, and *snow* result from a lowering of the temperature of the air below the dew-point. The most oppressive days in summer are those in which the air is nearly saturated with water vapor.

295. Humidity of the Air. — The *relative humidity* of the air is *the ratio between the amount of moisture present in the air and the amount that would be present if the air were saturated.*

If the temperature of the air is taken at the same time that the dew-point is determined, the relative humidity can be found by the help of the table in § 293. Suppose, for example, that at a time when the temperature of the air is 23° C. the dew-point is 17° C. From the table the amount of moisture present when the air is saturated at 17° C. is 14.339 g. per cubic meter. But at its temperature of 23° C. it could contain 20.355 g.; hence the relative humidity is 14.339 : 20.355, or about 70 per cent.

Instruments used in determining relative humidity are called *hygrometers.* The wet-and-dry-bulb hygrometer consists of two similar thermometers, the bulb of one being covered with a wick, the end of which dips into water. This keeps the covering of the bulb wet, and the rate of evaporation affects the temperature of the bulb. If there is little moisture in the air, the evaporation takes place rapidly, and the wet-bulb thermometer will read considerably lower than the other. Tables are provided, by the use of which the relative humidity can be determined from the readings.

296. Boiling. — If a quantity of fresh water is placed over a source of heat, the first effect will be the gathering of air bubbles on the sides of the dish. This comes from the air dissolved in the water. After a time these bubbles break away from the sides and bottom and rise to the surface. All this time the temperature of the water has been rising, which means that the velocity of the molecules within the liquid has been increasing. As this velocity increases the number of impacts of the molecules up against the surface of the water increases and there is a more rapid escape of water molecules into the air. A point is soon reached when the escape of these molecules in the form of steam is very rapid; the temperature now stops rising and the liquid is said to *boil.* Boiling is also called *ebullition.*

FIG. 252

Demonstrations. — Heat water in a beaker to about 50° and *remove the flame.* Fill a test tube half full of ether, insert a thermometer, and put them into the hot water, as in Fig. 252. Stir the water in the beaker with the test tube, and take the lowest temperature at which the ether boils, as its boiling point.

NOTE. — A flame must not be brought near the ether, as its vapor is very inflammable.

Make a similar experiment with alcohol and find its boiling point.

Fill a round-bottomed flask half full of water. Boil this over a Bunsen burner, and when steam is coming freely from the neck, remove the burner and put a stopper in the mouth of the flask. Invert the flask in a ring support, as shown in Fig. 253, and pour cold water over it. This will condense the vapor above the water and reduce the pressure upon its surface. As a result the water will

begin to boil vigorously, showing that if the pressure is reduced the boiling point is lowered.

The effect of reduced pressure upon the boiling point is seen upon high mountains, where water boils at so low a temperature that food cannot be cooked by boiling. Advantage is taken of this effect in the making of sugar, where vacuum pans are used to evaporate the solution without burning it. In the extraction of glue from bones and hides the pressure is increased and the boiling point correspondingly raised.

Fig. 253

297. The Spheroidal State. — Whenever water is thrown upon a very hot metallic surface, a condition called the *spheroidal state* is set up. The effect of the heated surface is to vaporize a little of the liquid, so that the remainder does not rest directly upon the metal, but upon a cushion of steam. This by its constant movement keeps the liquid in rapid vibration. The liquid takes the globular form because of surface tension, and changes into vapor at a rate faster than evaporation and slower than boiling. If the metal cools and the liquid comes in contact with it, a sudden production of steam is the result. Steam boiler explosions have resulted from the water in the boiler getting low, and then cold water being suddenly turned on after the boiler had become red-hot above the water line.

Demonstration. — Place a smooth tin or brass plate upon a tripod and heat it with a burner. Drop a few drops of water upon it with

a pipette. After the spheroidal condition is set up, remove the flame and let the plate cool. What occurs when the water touches the plate? Why?

298. Condensation of Vapors; Distillation. — The condensation of a vapor to a liquid is brought about by lowering its temperature or by increasing the pressure upon it, or by both. In condensing, it gives off as much heat as was required to vaporize it. It is possible to separate a liquid

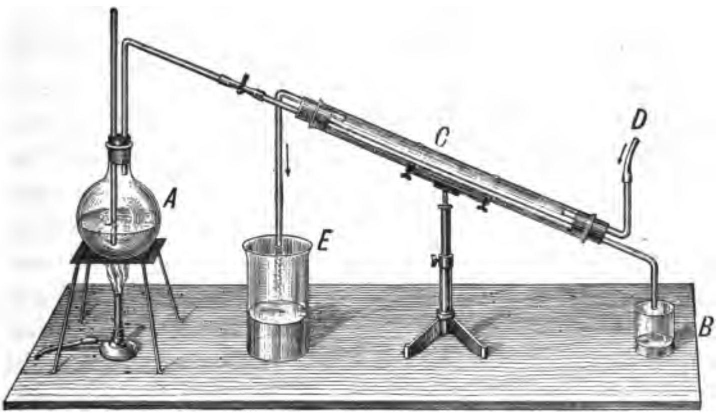


FIG. 254

from substances with which it is mixed, or which it holds in solution, by boiling the mixture or solution and condensing the vapor. This process, which depends upon the difference in the boiling point of liquids, is called distillation, and the liquid that has been purified by it is called the distillate. The condenser, in which the condensation takes place, may be in the form of a straight tube, as in Fig. 254, or in the form of a spiral tube, which is called a *worm*. Each form is surrounded by a water jacket to keep the tube cool. The purity of the distillate is increased by redistillation. In a mixture

of alcohol and water, for example, a little water comes over with the alcohol in the first distillation, but less in the second.

Demonstration. — Arrange apparatus as shown in Fig. 254. Pass cold water in at the lower end of the water jacket and let it run out at the top. Put a mixture of equal parts of alcohol and water in the flask. Boil it until about a third of the mixture is condensed in the beaker. Remove the flame and test the distillate by setting it on fire. Test the mixture remaining in the flask in the same way.

299. Fractional Distillation. — Since every liquid has its own boiling point, it is possible to separate a mixture of several that have different boiling points, by the process called *fractional distillation.* When crude petroleum is distilled, as soon as the boiling begins it is kept at the same temperature until no more distillate comes over. This most volatile part of the oil having been removed, the temperature is now raised a few degrees, boiling begins again, and the petroleum is kept at the new temperature as long as any vapor comes over. The process is repeated a number of times. The product that comes off last is the highest grade of all. That is it ignites at the highest temperature.

When air is liquefied and allowed to stand in a flask, the nitrogen will boil off first, since the boiling point of nitrogen is $-195°$, while that of oxygen is $-183°$. After the flask has stood for some time, the nitrogen will have boiled away and the liquid left will be oxygen.

300. Critical Temperature. — The pressure required to reduce a gas to a liquid increases as the temperature rises. Moreover, there is for every gas a temperature above which it cannot be liquefied, however great the pressure. This temperature is called the *critical temperature.*

Substance	Boiling Point (pressure = 760 mm.)	Critical Temperature
Water	+ 100° C.	+ 365° C.
Alcohol	78°	243°
Ether	38°	190°
Ammonia	− 33°	130°
Carbon dioxide	− 78°	31°
Oxygen	− 183°	− 118°
Air	− 191°	− 140°
Nitrogen	− 195°	− 146°
Hydrogen	− 253°	− 235°
Helium	− 268.6°	− 268°

Figure 255 is a graphical representation of the relation between the pressure, temperature, and physical state of ammonia.[1] This shows that ammonia can be reduced from a gas to a liquid by pressures varying from 115 atmospheres at the critical temperature, 130°, to 1 atmosphere when the temperature is reduced to − 33°. It also shows that ammonia can be reduced to a liquid at the ordinary temperature of the air by pressure alone.

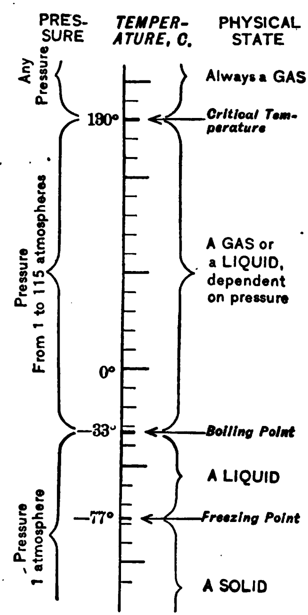


Fig. 255 — Physical State of Ammonia

301. Manufactured Ice. — In the making of manufactured ice,

[1] Sometimes called ammonia gas. The liquid "ammonia" in common use is really ammonia water; that is, water that has absorbed much ammonia.

the water to be frozen is poured into cans set in a large tank containing brine (Fig. 256). Coils of pipe are placed in the tank, and in these coils ammonia which has been liquefied by pressure is allowed to vaporize. The pressure is reduced by pumping the ammonia vapor back into the compressor. By the vaporization of the liquid and the rapid expansion of the vapor, the temperature of the brine is lowered to about

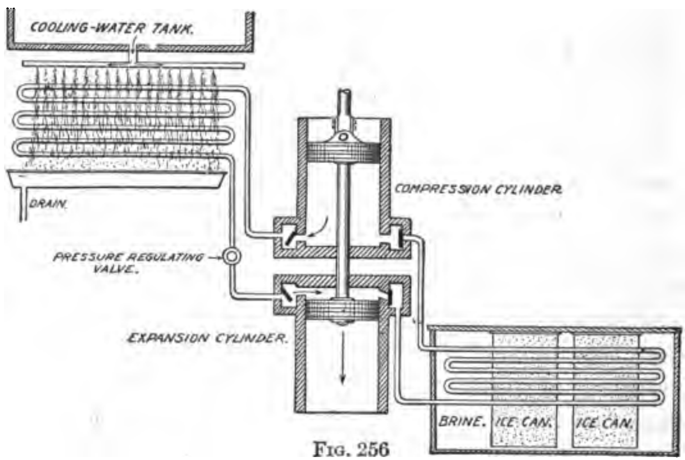


Fig. 256

– 10° C. The freezing of the water in the cans goes on rapidly, the crystals of ice extending from all sides. The heat produced in compressing and liquefying the ammonia is allowed to dissipate before the liquid ammonia is returned to the coils. The cooling of the compressed ammonia is brought about by causing cold water to drip over the pipes leading from the compression cylinder, before they connect with the expansion cylinder. This cools the ammonia before it enters the expansion cylinder and thus secures a lower temperature in the brine tank.

Questions

1. Why are the bolts of an iron bridge put in hot?

2. What takes place in the water of a pond as the weather grows colder in the fall?

3. Suppose a copper wire is fused into a glass tube. What will happen when they cool down to the temperature of the air?

4. Does the same thing happen if a platinum wire is used? Explain.

5. What will happen if the corner of a piece of ice is held in the top of a beaker of warm water? The result can be seen more readily if the water is slightly colored.

6. What takes place in a beaker of water that is being heated over a Bunsen burner if the burner is not under the middle of the beaker?

7. Is a football tighter in warm weather or in cold? Which is better, to fill the ball by blowing with the breath or to use an air pump? Why?

8. Why does decreasing the pressure on a given quantity of gas increase its volume?

9. Why does heating it have the same effect?

10. Why do water pipes burst when the water in them freezes?

11. Would increasing the pressure on ice at 0° C. melt it if the water did not expand on freezing?

12. What is the effect of placing a beaker of water at 80° C. under the receiver of an air pump and then exhausting the air?

13. Why does moisture collect on a window pane in cool weather?

14. Why is sea water distilled before being used in the boilers of a steamship?

15. Why does evaporation take place more slowly when the air is moist?

16. Why do wet clothes freeze dry on a cold day in winter?

17. Why does a wet road dry sooner if the wind blows?

18. Why are the cans, containing water to be frozen in an ice machine, placed in brine instead of in water?

19. Describe and explain the action that takes place in each part of the refrigerating machine shown in Fig. 256 and state the reason for the direction of flow in the pipes.

Problems

1. How much will a steel rail 30 ft. long increase in length when the temperature changes from zero to 22° C.?

2. If a metal rod 150 cm. long at 0° C. expands 0.24 cm. on being heated to 100° C., what is its coefficient of linear expansion?

3. How much would a meter scale made of invar expand on being heated from − 20° C. to + 28° C.?

4. The density of ice is 0.917. What will be the volume of a cubic foot of water after freezing?

5. A balloon contains 4000 cu. ft. of gas at 23° C. What will be the volume of the gas at 0° C.?

6. If the volume of an inclosed body of air is 426 c.c. at zero what will it be when the temperature is raised to 20° C., the pressure being the same?

7. If the volume of a gas at 21° C. and a pressure of 950 mm. of mercury is 126 c.c., what will it be at 0° C. and a pressure of 760 mm.?

8. The pressure per sq. cm. on 150 c.c. of gas at 16° C. is 3.2 kg. What must it be to reduce the volume to 120 c.c. when the temperature is 23° C.?

9. The temperature of 200 c.c. of gas at a pressure of 760 mm. of mercury is 21° C. What will it be if the volume is reduced to 150 c.c. by a pressure of 1140 mm.?

10. What would the temperature have been in problem 9, if the pressure used to reduce the volume of the gas had been two atmospheres, or 1520 mm.?

11. Which contains the greater amount of moisture, air at 15° C. having a humidity of 90% or air at 23° C. with a humidity of 60%?

12. How much moisture condenses from a cubic meter of air that is saturated at 20° C. when the temperature falls to 8° C.?

13. On a day when the temperature of the air was 20° C. the dew-point was found to be 11° C. What was the relative humidity?

14. If the humidity is 80% and the temperature of the dew-point is 16° C., how much moisture is in the air per cubic meter? How much would it hold if saturated, and what was the temperature of the air?

IV. CALORIMETRY

302. The Measurement of Heat. — In order to measure the quantity of heat that is given to a certain amount of water, two things must be considered: the mass of the water and the change of the temperature.

Since there are different units of mass and different thermometric scales, several thermal units are possible. The two most important are defined as follows: the quantity of heat required to raise 1 g. of water through 1° C. is called a *calorie;*[1] the quantity of heat required to raise 1 lb. of water through 1° F. is called a *British thermal unit* (B. T. U.). 1 B. T. U. = 252 calories. The measurement of the heat used in changing either the temperature or the physical condition of a body is called *calorimetry.*

303. Specific Heat. — **Demonstration.** — Place 50 g. of shot in one test tube and 50 g. of iron filings in another similar tube. Raise both to the same temperature by placing them in a beaker of hot water. Into each of two small beakers pour 100 g. of water that has been cooled to the zero point by means of ice. Pour the shot into one beaker and the filings into the other. Take the temperature of the water in each, and it will be found that the filings have given to the water the greater amount of heat, as is shown by the higher temperature in the beaker containing them.

This demonstration shows that iron has a greater amount of heat than lead at the same temperature. It follows that more heat would be needed to raise 50 g. of iron 1° in temperature than to raise 50 g. of lead 1°.

The ratio between the quantity of heat required to raise the temperature of a certain mass of any substance one degree, and the quantity of heat required to raise the same mass of water

[1] French engineers also use a calorie 1000 times as great; *i.e.*, 1 kg. of water is the basis instead of 1 g.

one degree, is the specific heat of that substance; or, *the specific heat of a substance is the number of calories required to change the temperature of 1 g. of that substance 1° C.*

TABLE OF SPECIFIC HEAT

Air (conts. pres.)	0.237	Aluminum	0.214
Water	1.000	Flint glass	0.117
Ice	0.502	Iron	0.113
Steam	0.480	Copper	0.094
Ether	0.516	Mercury	0.033
Alcohol	0.620	Lead	0.031

304. The Measurement of Specific Heat. — A convenient method of measuring the specific heat of a body is the *method of mixtures.* This depends upon the fact that when two bodies that are at different temperatures are put together, the temperature of one will fall and that of the other will rise until they have reached the same temperature. It also depends upon the principle that *the heat absorbed by the cool body in heating is exactly the amount given out by the hot body in cooling.* This principle is fundamental in all work in specific heat and may be stated in its simplest form as follows: *Heat gained = Heat lost.* The quantity of heat absorbed by the cool body in heating = mass × change in temperature × specific heat. The quantity of heat given out by the hot body in cooling = mass × change in temperature × specific heat. That is,

$$Mts = M't's'. \qquad (50)$$

EXAMPLE. — Two pounds of fine shot at 90° were poured into one pound of water at 15°, and the resulting temperature was 20°. What was the specific heat of the shot?

From Formula 50, since the specific heat of water = 1,

$$1 \times 5 \times 1 = 2 \times 70 \times s,$$

$$\text{whence } s = \frac{5}{140} = .036.$$

305. Water Equivalent. — It is evident that in all similar measurements, account should be taken of the change in temperature of the containing beaker, or calorimeter. In order to do this it is necessary to find its *water equivalent*, or the mass of water that will require the same number of calories to raise its temperature one degree as the beaker requires. Numerically this is the product of the mass of the beaker by its specific heat.

Example. — Copper shot weighing 500 grams at a temperature of 80° C. was poured into a 20 g. aluminum beaker containing 300 g. of water at 60° C. What was the resulting temperature?

Water equivalent of beaker = $20 \times 0.214 = 4.28$. Hence,

$$(300 + 4.28)(t - 60) \times 1 = 500\,(80 - t)\,(0.094)$$
$$304.28\,t - 18{,}256.8 = 3760 - 47\,t$$
$$351.28\,t = 22{,}016.8$$
$$t = 62.7^\circ$$

306. Heat of Fusion. — If heat is applied to a beaker of crushed ice, it will be noticed that while the ice is being melted the temperature of the resulting water is the same as that of the ice, *i.e.*, zero. The effect of the heat is not to change the temperature, but to change the physical state from solid to liquid.

The number of heat units required to melt a unit mass of a substance without raising its temperature is called the *heat of fusion* of the substance. On solidification, the same amount of heat is given out.

Demonstration. — Pour 500 g. of water at 80° C. into a glass beaker weighing 100 g., and into this put 150 g. of cracked ice as dry as possible. Stir the ice until it is melted and take the resulting temperature of the water. It will be found to be about 43.8° C. The heat of fusion of ice can now be calculated as follows:

The heat given out by the 500 g. of water and by the 100 g. of

glass in losing 36.2° of temperature is used in melting the ice and raising the resulting water to 43.8°.

Heat given out by the water $= 500 \times 36.2 \times 1 = 18{,}100$ calories.

Heat given out by the beaker $= 100 \times 36.2 \times .117 = 424$ calories.

Total heat given out $= 18{,}524$ calories.

Heat taken up by ice in melting $= 150 \times$ heat of fusion $= 150\,F$ calories.

Heat taken up by resulting water $= 150 \times 43.8 \times 1 = 6570$ calories.

$$150\,F + 6570 = 18{,}524.$$
$$150\,F = 11{,}954.$$
$$F = 79.7.$$

The heat of fusion of ice, as found by careful experiments, is 80 calories. This means that it takes as much heat to melt one gram of ice as it would to raise one gram of water from 0° to 80°.

307. Heat of Vaporization. — When heat is applied to a beaker of water, its temperature will rise until the boiling point is reached. After this no further increase in the temperature will take place, however rapid the boiling. By continuing the experiment, the water can all be changed into vapor. The number of heat units required to vaporize a unit mass of liquid without changing its temperature is its *heat of vaporization.* When the vapor changes to a liquid, the same amount of heat will be given out. Experiment has shown that the heat of vaporization of water is 537 calories. This means that the heat required to boil away 1 g. of water is 5.37 times as much as is required to raise its temperature from zero to 100°.

308. Curve of Heat Effects. — An effective way of showing the relation between the heat units applied and the

effects produced is indicated in Fig. 257. This shows graphically the relation between the heat units and the changes produced when heat is applied to 1 g. of ice at $-18°$ and continued until the latter is changed into steam at 120°. Horizontal distances represent calories or heat units (H. U.), and vertical distances represent changes of temperature.

Since the specific heat of ice is 0.502, $Mts = 1 \times 18 \times 0.502$ = about 9 calories required to raise the ice to zero. 80 calories will be required to melt it; $1 \times 100 \times 1 = 100$

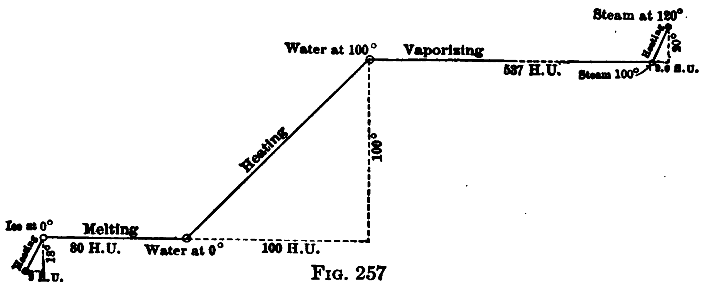


FIG. 257

calories to raise the water to 100°; 537 calories to vaporize it; and, since the specific heat of steam is 0.48, $Mts = 1 \times 20 \times 0.48 = 9.6$ calories to raise the steam to 120°. The total heat applied will be the sum of these amounts, or 735.6 calories.

A study of this curve will be of great assistance in making clear the relation between heat units, specific heat, heat of fusion, and heat of vaporization, and will help in the solution of problems that include these quantities.

Questions

1. Suppose you were making a number of determinations in specific heat, would there be any advantage in using the same calorimeter for them all?

2. What do t and t' mean in the equation $Mts = M't's'$?

3. What effect does the high specific heat of water have upon the rate at which the temperature of a lake will be changed?

4. If the temperature of a room is – 4° C., what will be the result of bringing pans of water into it?

5. Will it take longer to melt a piece of ice or to raise the resulting water to the boiling point, if the heat is uniformly applied?

6. What do horizontal parts of the curve of heat effects, Fig. 257, mean?

Problems

1. How many calories are required to heat 200 g. of water from 15° C. to the boiling point?

2. How many B.T.U. are required to heat 5 lb. of water from 50° F. to the boiling point?

3. A piece of nickel at 100° C. was dropped into an equal weight of water at 0° C. and the resulting temperature was 9.8° C. Find the specific heat of the nickel.

4. What is the water equivalent of a glass beaker weighing 80 g.?

5. What is the water equivalent of a copper calorimeter of the same weight?

6. What is the water equivalent of an aluminum calorimeter of the same weight?

7. A beaker whose water equivalent is 14 g. has in it 120 g. of water at 14° C. What is the resulting temperature when 56 g. of water at 90° C. is poured into it?

8. Into the same beaker, containing 50 g. of water at 96° C., 200 g. of mercury at 20° C. is poured. Find the resulting temperature.

9. An aluminum beaker weighing 10 g. contained 250 g. of water at 12° C. What was the resulting temperature when 250 g. of water at 92° C. was poured into it?

10. What mass of water at 90° C. will just melt 2 kg. of ice at 0°?

11. It takes 10 minutes to melt a piece of ice. How long will it take to raise the resulting water to the boiling point over the same source of heat?

12. How many calories will it take to melt 120 g. of ice and raise the resulting water to 16° C.?

13. How many B.T.U. will it take to melt 6 lb. of ice and raise the resulting water to 48° F.?

14. The normal temperature of the body is 98.4° F. How many calories are required to raise a drink of 300 g. of ice water to that temperature?

15. It takes 8 minutes to raise the temperature of a certain quantity of water from the freezing to the boiling point. How long will it take to boil the water away?

16. How much steam at 100° C. must be mixed with 1 litre of water at 18° C. to raise its temperature to 90° C.?

17. How many calories would be required to melt 40 g. of ice at zero, raise the resulting water to 100° C., and vaporize it?

18. How many grams of ice would be required to change the temperature of 1200 g. of water from 60° F. to 40° F.?

19. A cubic foot of snow melts into about one tenth of a cubic foot of water. How many B.T.U. of heat would be required to melt the snow from a space 10 ft. square if it were 1 ft. deep? Could snow be removed from the streets economically by this method?

V. HEAT AND WORK

309. General Law. — We have seen that both friction and collision give rise to heat. The work required to overcome the friction in a machine is, from the mechanical standpoint, lost work; in reality it is work transformed into heat. The relation between mechanical work and heat was investigated by Joule, who established the following principle: *The disappearance of a certain amount of mechanical energy produces an equivalent amount of heat.* The converse of this law is equally true: *The disappearance of a certain amount of heat produces an equivalent amount of mechanical energy.*

310. The Mechanical Equivalent of Heat. — The number of units of work required to produce one heat unit is called the *mechanical equivalent of heat.* Joule's experiments determined that the number of foot pounds of work neces-

sary to heat 1 lb. of water 1° F. is 772, or to heat 1 lb. of water 1° C. is 1390. This is called *Joule's equivalent*. More recent determinations by Rowland give 778 and 1400 instead. To heat 1 kg. of water 1° C. requires 427 kilogram-meters of work.

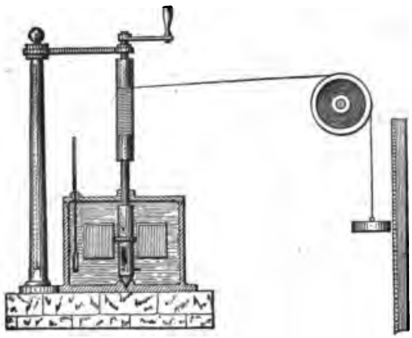


FIG. 258

Joule's method was as follows: A cord attached to a weight was run over a fixed pulley and wound around the axle of a wheel, with paddles at the other end of the axle. This was arranged so that, on letting the weight fall, the paddles were caused to rotate in a known quantity of water in a vessel. The weight multiplied by the distance through which it falls gives the mechanical work, and the mass of water multiplied by the change of temperature gives the heat units. Joule's experiment showed that a 10-lb. weight falling through 77.2 ft. would raise the temperature of 1 lb. of water through 1° F.

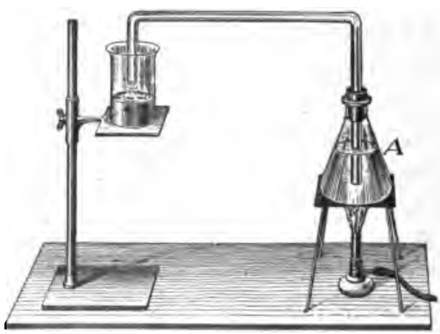


FIG. 259

311. The Pressure of Water Vapor. — **Demonstration.** — Place a quantity of water in the flask A (Fig. 259). Raise the water to the boiling point, and after it has boiled a short time remove the flame

and put in a rubber stopper with tube, as shown in the figure. Replace the flame, and the steam formed by boiling will collect in the flask above the surface of the water and increase the pressure. As this pressure increases it will do work by forcing water out of the tube.

In the process of evaporation the molecules, moving in every direction, strike the surface of the liquid from below, and some of them escape into the air. If the temperature is raised, the velocity of the molecules is increased, and a

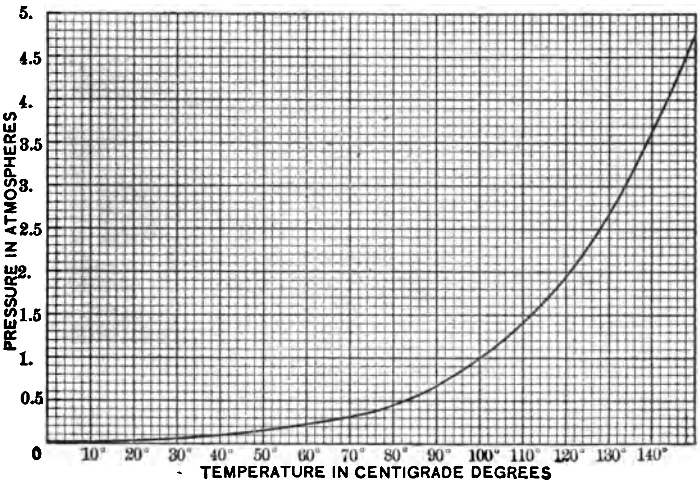


FIG. 260. — Pressure of Water Vapor at Different Temperatures

greater number escape. When boiling begins, at 100° under ordinary atmospheric pressure, the rise of temperature is stopped, and all the heat energy applied is used in changing water to steam. If the boiling takes place in a closed vessel, the repeated blows of the molecules of the vapor upon the surface of the liquid oppose the escaping molecules more and more as the vapor increases in quantity and pressure; and if the temperature is kept at any fixed point, as 100°,

the boiling soon stops. If the temperature is raised, the molecular velocity increases, the internal pressure becomes greater than the vapor pressure, and boiling recommences.

312. The Steam Engine. — A steam engine is a machine for transforming the pressure and expansive power of steam into mechanical energy. Since the steam is produced by the application of heat, the steam engine really transforms heat into mechanical energy. So great, however, are the losses in the burning of the coal, the expansion of the

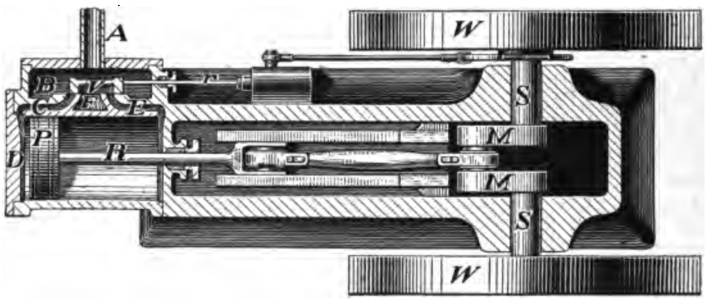


Fig. 261. — Steam Engine, seen from above

steam, and the working of the engine, that the best modern steam engine does not utilize more than 17 per cent of the energy in the coal.

A simple form of steam engine is shown, partly in section, in Figs. 261 and 262. *A* is a steam pipe connecting a boiler with the steam chest *B*. The live steam passes from the steam chest through the port *C* into the left end of the cylinder, between the cylinder head *D* and the piston *P*. The pressure of this live steam forces the piston to the right, and drives the exhaust steam, on the other side of the piston, out of the port *E* under the slide valve *V*, and out of the exhaust port *F*, which leads either to a condensing chamber or to the open air.

When the piston has been forced over a part of its stroke, the slide valve will be moved by its rod *r* to the left, closing *C*, and the work done during the rest of the stroke will be due to the expansive power of the steam. By the time the piston has reached the end of its stroke to the right, the slide valve will be moved so far to the left that the live steam will now come into the right end of the cylinder through *E*, and the exhaust steam in the left end will go out of the ex-

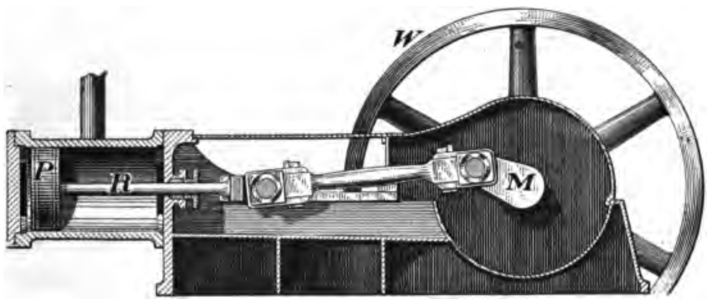


FIG. 262.—Steam Engine, seen from side

haust port *F*, through the port *C*. The piston rod *R* is attached to a crank arm *M* on the main shaft *S*, and in this way the to-and-fro, or reciprocating, motion of the piston is changed to the rotary motion of the shaft. On the shaft are fixed one or two heavy flywheels *W*, the momentum of which serves to give steadiness to the engine; and one or more belt wheels, over which run the belts by which the motion of the shaft is transmitted to machinery.

In *condensing* engines the exhaust steam passes into a compartment containing water for condensing the steam. The condensation greatly reduces the *back pressure* which opposes the motion of the piston. In noncondensing en-

gines, such as the locomotive, the exhaust steam passes into the open air — sometimes by way of the smokestack, in order to increase the draught through the fire box. The back pressure in noncondensing engines is the pressure of the atmosphere.

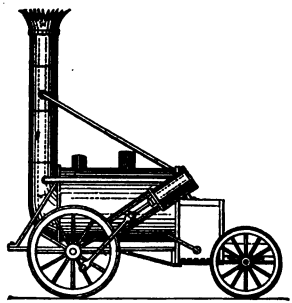


FIG. 263. — The Rocket

In *compound* engines, the steam gives up only part of its heat and expansive power in one cylinder; the exhaust steam from this escapes under pressure to a second cylinder, where it does more work. By thus using two or more cylinders in succession, a greater percentage of the energy of the steam can be utilized. A comparison of Stephenson's locomotive, the Rocket, built in 1829 (Fig. 263), with a modern type of locomotive (Fig. 264), shows the development that has taken place.

313. The Steam Turbine is another kind of steam engine, in which expanding steam strikes directly upon curved blades in a wheel, causing it to rotate by impact or by reaction, just as the turbine water wheel does (§ 147). The principle of a simple turbine is illustrated in Fig. 265, which shows how steam is delivered to the blades of the wheel through four tubes. In each of these tubes there is a check valve which permits only the proper amount of steam to pass through. On escaping through this, the steam acquires a high velocity in expanding, and strikes upon the blades of the wheel with great force.

Another type of turbine is divided into stages; that is, there are several rotating wheels for each set of steam pipes.

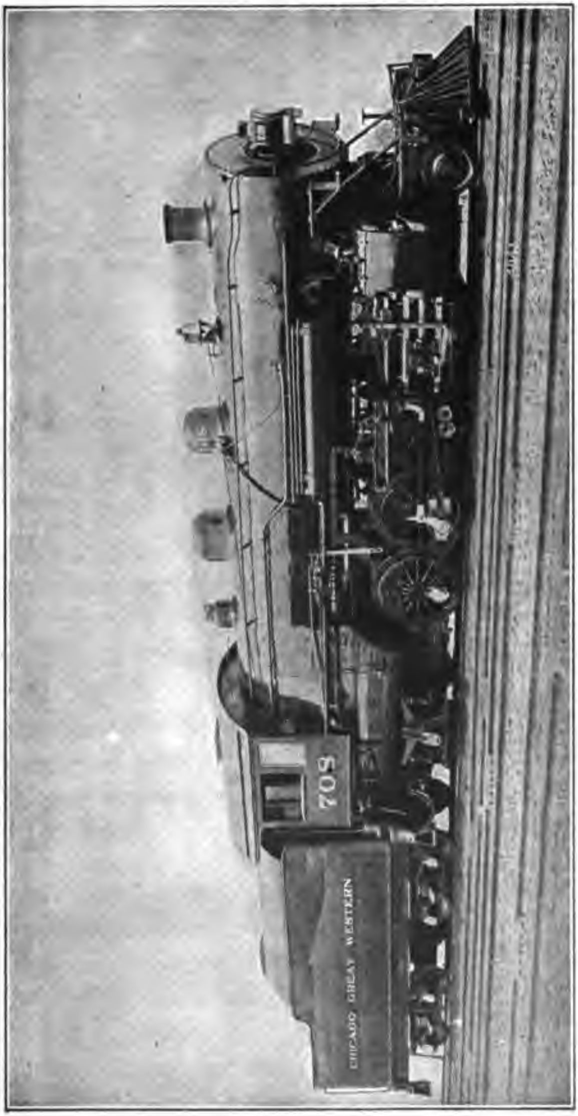


FIG. 264. — A Modern Locomotive

Figure 266 shows how the steam may be passed from the steam nozzles *N* through three sets of moving blades *M* by

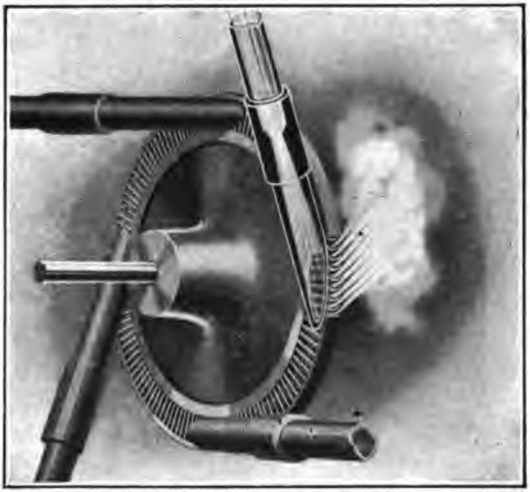


Fig. 265.—A Simple Steam Turbine

the use of two sets of stationary blades *S*. By this arrangement the energy of the steam is used with a high degree of efficiency. The steam turbine is used to drive the dynamos in some of the largest plants for the generation of electric current.

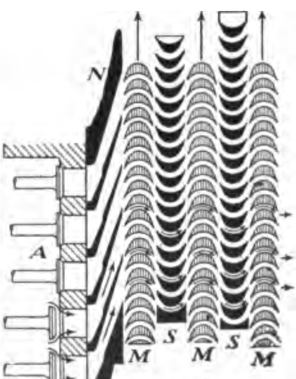


Fig. 266

314. Gas Engines.—In a gas engine the motive power is the expansion caused by the explosion of a mixture of gas and air in a cylinder. The expanding gases work against a moving piston as the expanding steam does in a recipro-

cating steam engine. The cycle of operations in a four-stroke or four-cycle engine is briefly as follows (Fig. 267):

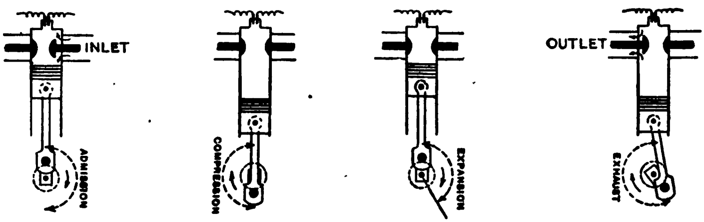


Fig. 267

On the first, outward, stroke of the piston the inlet valve is opened and a mixture of gas and air enters the cylinder through the inlet. On the return stroke the mixture is compressed. When the piston begins its third stroke, which is the second outward stroke, the gas is exploded by an electric spark and expands, and on the fourth stroke the outlet valve is opened and the products of the combustion are driven from the cylinder through the outlet. The third stroke is the only one from which power is obtained.

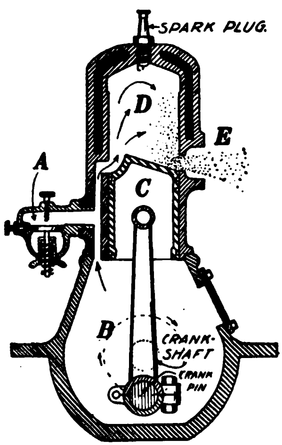


Fig. 268

In the two-cycle engine the mixed gases enter the crank case *B* through the port *A*, Fig. 268, when the piston *C* is at the top of its stroke during which the gas in the cylinder *D* is compressed. The spark explodes the gas, driving the piston downward and compressing the gas in the crank case. The gas from the crank

case passes through the transfer port as shown by the arrows, and forces the exploded gas out of the exhaust port E. Both ports are closed as the piston begins its upward motion and the rest of the stroke completes the compression.

315. The Automobile. — The gasoline automobile is an excellent example of a self-contained means of transportation.

Its essential parts are the chassis, comprising the frame with running and steering gears; the motor, an internal combustion gasoline engine; the transmission system, by means of which the energy developed in the engine is applied to the wheels as work; the ignition and lighting systems; and the lubrication and cooling systems.

Since the frame of an automobile is subjected to severe strains, manufacturers use for this purpose an alloy of steel that has been given its maximum tensile strength by means of a heat treatment.

The engines are of many forms, varying in the number of cylinders. The operation of the piston in a four-stroke engine is shown in Fig. 267. The gasoline and air are mixed in proper proportions in the carburetor, and ignition in the cylinders is produced by electric sparks.

The transmission system includes the speed-shifting gears and the shafts and gears required for changing the reciprocating movement of the pistons of the engine into the rotation of the rear wheels of the chassis.

Cooling systems are of various kinds, some employing a draft of air forced past the radiator, others a forced current of water, and still others a water circulation which depends upon the difference between the specific gravity of cold and of hot water.

A cross section of the engine, transmission, etc., of a much-used type of car is shown in detail in Fig. 269. Figure

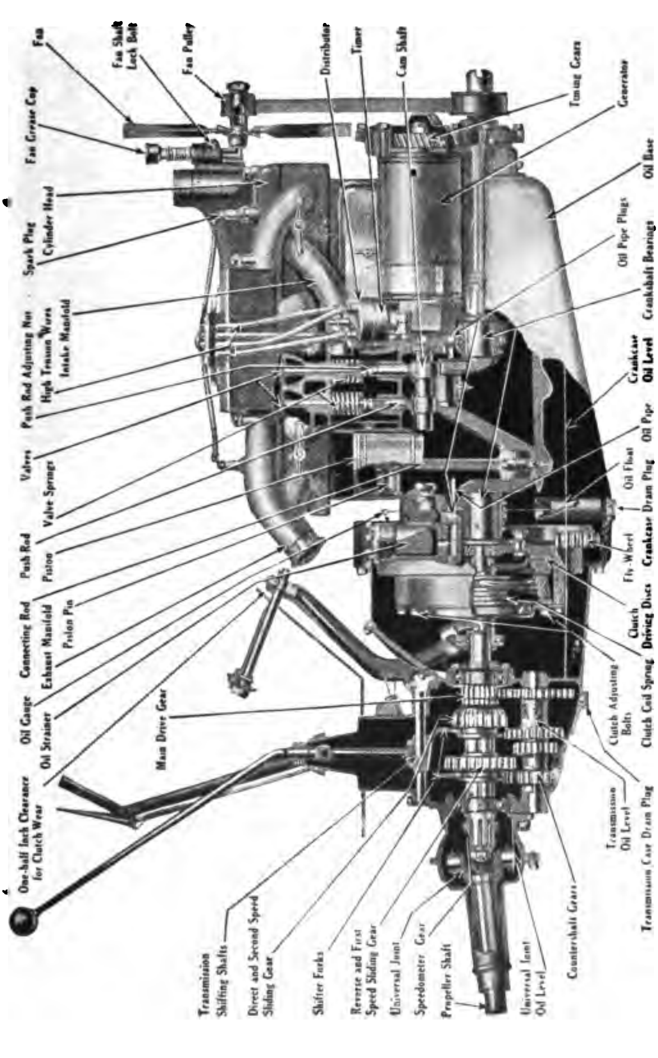


FIG. 269. — Automobile Engine and Transmission

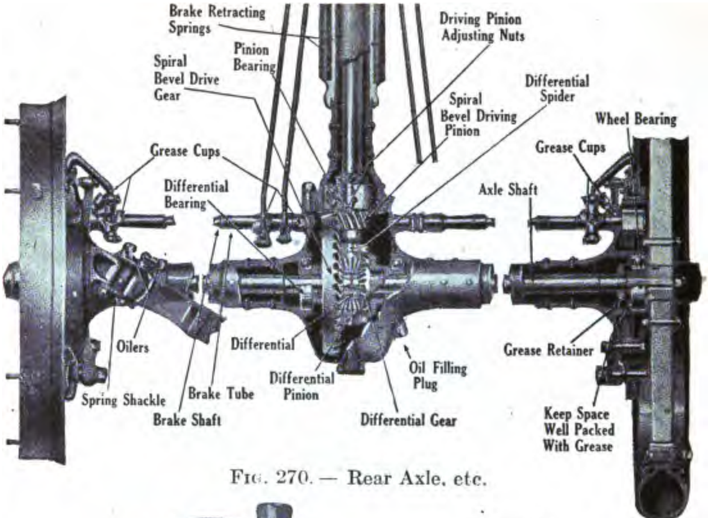


FIG. 270. — Rear Axle, etc.

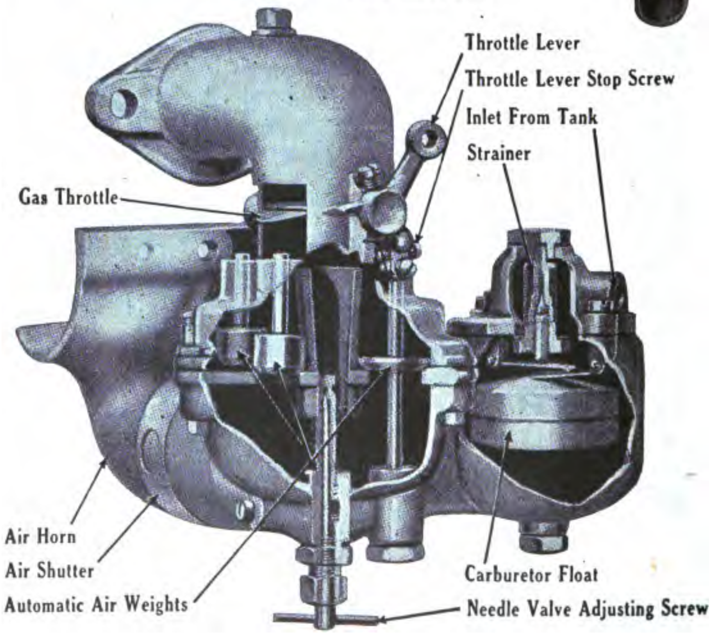


FIG. 271. — Carburetor

270 shows details of the mechanism of the rear axle and its accessories. One form of carburetor is shown in Fig. 271.

Questions

1. What is "lost work" in a machine?

2. What is meant by the term "mechanical equivalent of heat"?

3. What is the effect of raising the temperature upon the expansive power of steam?

4. What is the cause of the sparks that fly from the driving wheels of an engine when the brakes are put on?

5. Which is greater at the same temperature, the pressure of water vapor, or the pressure of ether vapor? Why?

6. Explain why water boils at a lower temperature under reduced pressure.

7. Why is the water in a steam boiler at a higher temperature than 100° C.?

8. The successful use of automobiles and airplanes depends upon the gasoline engine. Why?

Problems

1. How many foot pounds of work must be done on 5 lb. of water to raise its temperature 15° C.?

2. 56,000 foot pounds of work were expended on 4 lb. of water. What was its rise of temperature in Fahrenheit degrees?

3. 31,120 foot pounds of work were expended in raising the temperature of a certain quantity of water 8° C. How much water was there?

4. Suppose the 500-lb. head of a pile driver falls 25 ft., and that 20 per cent of the kinetic energy on striking is converted into heat. What change of temperature, in Fahrenheit degrees, would be given to 1 lb. of water by the heat generated?

5. Suppose the average pressure of the steam that is used in an engine is 60 lb. per square inch, the piston head is 10 in. in diameter, and the stroke of the piston is 18 in. How many foot pounds of work are done at every stroke of the piston? How many at every rotation of the flywheel? How many per minute if the speed is 106 revolutions per minute? What is the horse power of the engine?

CHAPTER VIII

MAGNETISM

316. Natural Magnets. — Pieces of a certain kind of iron ore have the property of attracting iron; and when suspended so as to swing freely, they will come to rest in a nearly north-and-south direction. They are called *natural magnets*. The ore is called *magnetite*, from Magnesia in Asia Minor near which it was first found.

317. Artificial Magnets. — **Demonstration.** — Select a sewing needle that has no attraction for iron. Rub it gently from the middle toward the point across one end of a natural magnet (a bar magnet will serve as well); then rub the other half across the other end of the magnet. Hold one end of the needle near some iron filings. They will be found to cling to the needle.

A piece of iron or steel that has the property of attracting iron as in the above demonstration is called an *artificial magnet*. This name is not very appropriate, and is used simply to distinguish magnets composed of manufactured iron or steel from natural magnets.

Artificial magnets are made in various forms. A bar magnet is a straight bar; a horseshoe magnet is a bar bent into U shape.

318. Permanent and Temporary Magnets. — **Demonstration.** — Repeat the above demonstration, using a bar of soft iron instead of the steel needle. Does the bar become a magnet? Now hold one end of a soft iron bar on or near the end of a magnet, and bring the other end of the bar near some iron filings. What is the result?

Pieces of soft iron can be made to act as *temporary magnets* while near another magnet, but they retain hardly any magnetism after the other magnet is removed. Pieces of steel retain their magnetism to a great degree and hence can be made into *permanent magnets.*

319. Magnetic and Nonmagnetic Substances.—Demonstration. — Place on a table a collection of a dozen different materials, nails, screws, pins, coins, pencils, wire, paper, etc., — and try to pick them up with a magnet. Part of them will be picked up, but upon others the magnet will have no effect whatever.

Those substances that are attracted by a magnet are called *magnetic substances,* while those that are not attracted by it are called *nonmagnetic substances.* Iron and steel are magnetic; also, to a less degree, nickel and cobalt. Some ores of iron are magnetic, while others are not. Nonmagnetic iron ores can be made magnetic by being strongly heated, as in the flame of a blowpipe.

320. Polarity.—Demonstrations.—Lay a bar magnet upon a table covered with small nails, and then lift it by the middle. It will be found that the nails cling to the magnet, the greater number being near the ends, as in Fig. 272. The two points near the ends where the most nails cling indicate the position of the *poles* of the magnet.

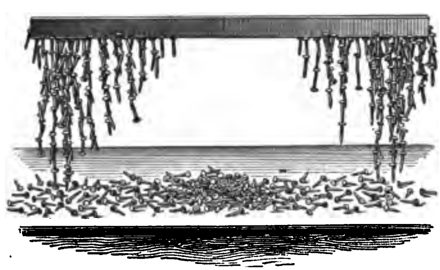


FIG. 272

Suspend the bar magnet by a thread attached to its middle point, and after swinging back and forth for a time it will finally come to rest in a direction that is nearly north and south.

It has been agreed to call the end which points to the magnetic north the + or *north pole* and the other the − or *south pole*. The strictly correct names would be *north-seeking pole* and *south-seeking pole*. A body with such poles is said to be *polarized*, and to possess *polarity*.

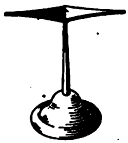


Fig. 273

321. The Magnetic Needle is a small bar magnet suspended by a thread or balanced upon a pivot (Fig. 273). It is used in many instruments, as in the compass. If we should continuously follow the direction in which it points, our path would be a *magnetic meridian;* and that spot in the Arctic regions where all magnetic meridians meet is called the *north magnetic pole.*

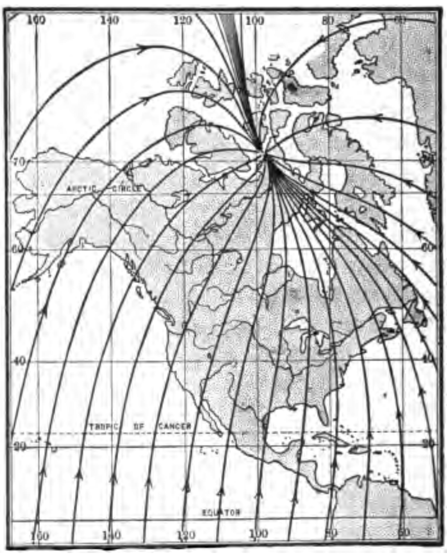


Fig. 274. — Magnetic Meridians

Demonstrations. — Magnetize a sewing needle by drawing it across the ends of a bar magnet. Begin the stroke at the middle of the needle and end it at the point, drawing it across the + end of the magnet. Do this ten or twelve times. Reverse the needle and draw it across the − end of the magnet, beginning at the middle of the needle and ending at the eye. Unravel a fine silk thread, and tie a single strand around the middle of the needle. When you have balanced the needle so that it will hang horizontally, fasten

the thread in place by a bit of beeswax or sealing wax, and you have a magnetic needle that will serve for many experiments.

Suspend the needle and find the magnetic meridian. Observe which end of the needle points north, and notice whether or not it is the end that was drawn over the north end of the magnet.

Make a small bar magnet out of a good-sized knitting needle. In stroking it with the magnet, lay it upon a piece of board and stroke it with the + end from the middle to one end of the needle. Reverse the needle and magnet and repeat. In order to make a strong magnet, the steel must be stroked a great many times. Test it with iron filings and nails.

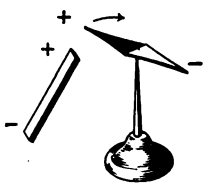


Fig. 275

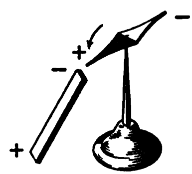


Fig. 275 *a*

322. Mutual Action of Magnets. — **Demonstration.** — Bring the + end of a bar magnet near the + end of a magnetic needle and note the result. Bring the − end of the magnet near the + end of the needle and observe. Make the same experiment on the − end of the needle.

The results of the above demonstration may be stated in the following terms: *Like poles repel and unlike poles attract each other.* This law is a fundamental one in magnetism and should be made very familiar. *The force of the repulsion or the attraction varies directly as the magnetic strength of the poles and inversely as the square of the distance between them.*

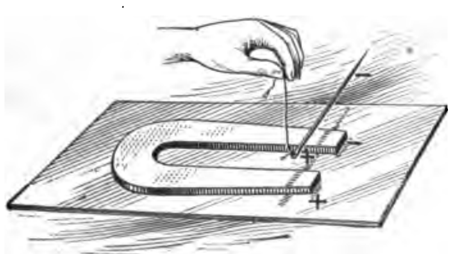


Fig. 276

Demonstrations. — Lay a horseshoe magnet upon a table. Pass a light thread through the eye of a magnetized sewing needle, and

by careful manipulation it can be brought to remain in a horizontal position over the ends of the magnet, as in Fig. 276, although only slightly supported at one end. Explain.

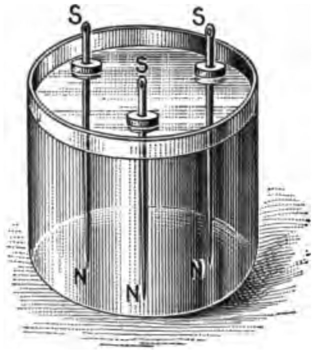


FIG. 277

Magnetize a number of sewing needles so that their eyes will be south poles and their points north. Thrust them through small corks, leaving the eye half an inch above. Float three of them in a glass of water. Notice their positions, and explain. Now bring the south pole of a bar magnet vertically down over the middle of the glass. Explain the result. Reverse the magnet and repeat. Explain. Increase the number of needles and repeat. These are called *Mayer's floating magnets*.

323. The Distribution of Magnetism in a Magnet may be found by laying a bar magnet upon a table, suspending above it a magnetized sewing needle, and passing the needle from end to end. At the middle of the magnet the needle will be parallel to it. This is called the *neutral point*, which may be defined as that point in a magnet where all the lines of force are within the magnet, none of them passing into the air. At other points the needle will dip more or less, as in Fig. 278. At two points near the ends the needle stands practically vertical; these points locate the poles.

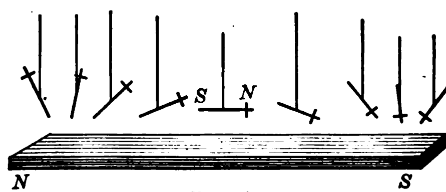


FIG. 278

324. Lines of Force. — A north magnetic pole placed near

the + end of a bar magnet is at the same time repelled by the + end and attracted by the − end, and each force varies inversely as the square of the distance. Consequently, if the pole were free to move under the sole influence of the bar magnet, it would follow a curved path called a *line of magnetic force*, and would come to rest in contact with the − end of the magnet. By starting the pole at different points, an infinite number of such lines of force could be described. The *direction* of a line of force means the direction in which a free north pole would move. Though a free north pole cannot exist (there is no north pole without its accompanying south pole), this direction at any point will be that along which the north pole of a short piece of magnetized needle suspended by a thread will tend to move. This needle will turn so as to lie as nearly as possible in the line of force, because in any other position the forces acting on the two poles of the needle, not being in line with the needle, would form a couple and cause rotation. A few lines of force are shown in Fig. 279, some complete and some in part.

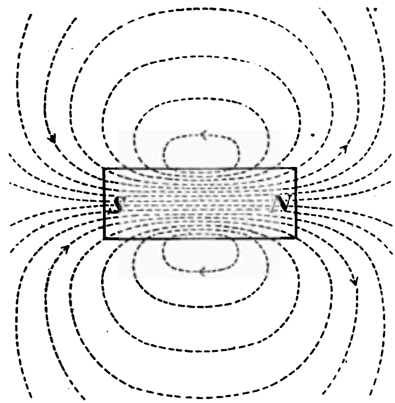


FIG. 279. — Lines of Force

Demonstration. — Lay a bar magnet upon the table and cover it with a sheet of white paper. Put over this a thin glass plate and sift iron filings evenly over it. The sieve for this purpose can be made by melting the solder that holds on the bottom of a tin can, removing the bottom, and tying over the can, in its place, a piece of

Rev.

thin muslin or cheesecloth. Rap the plate gently with a lead pencil; the filings will move at every blow, and will arrange themselves in lines that show clearly the paths of the lines of force.

Suspend a half-inch piece of magnetized sewing needle quite near the plate used in the above demonstration. Notice that it places itself in line with the filings.

325. A Permanent Record of Lines of Force may be made by repeating the above demonstration in a dark room with a ruby lantern for light, and using an ordinary photographic dry plate for the glass plate. The dry plate is placed upon the magnet, film side up, the filings are sifted upon it, and the plate is rapped until the position of the lines of force is clearly brought out. The exposure is made by burning a match about a foot above the plate. On developing the plate in the usual way a negative is obtained from which may be made prints showing the lines formed by the filings.

326. Magnetic Permeability. — **Demonstration.** — Repeat the demonstration in § 324, after laying a soft iron bar beside the magnet. What effect does this have on the lines of force?

Lines of force pass through air and other nonmagnetic substances with greater difficulty than through iron. When a piece of iron is introduced into a space where there are lines of magnetic force, it offers a path of less resistance, and causes a distortion of the lines of force from their previous distributions. The iron, offering a smaller resistance to the passage of the lines of force than the air, is said to have a greater *permeability*. For this reason a watch in a thin iron case does not become magnetized.

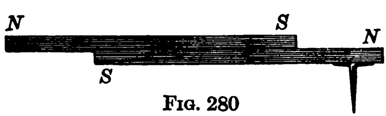


Fig. 280

Demonstration. — Suspend a nail from near one end of a bar magnet, as in Fig. 280. Slide a second magnet of equal strength

over it and observe results. Reverse the second magnet, and again slide it over the first. Explain both results.

327. Action of Lines of Force. — The conception of lines of force is that *they form closed circuits* (being continued through the substance of a magnet as in Fig. 279), *take the path of least resistance, tend to shorten like stretched rubber bands, and when going in the same direction mutually repel each other.*

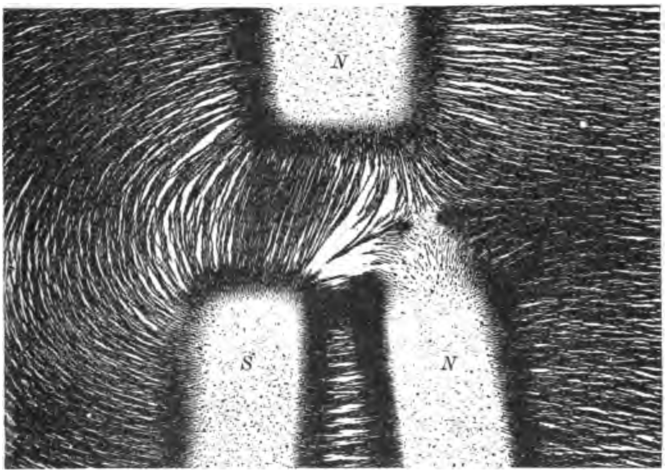


Fig. 281

The repulsion between lines of force going in the same direction is illustrated in Fig. 281, which shows the lines formed, by the method of § 325, on a plate laid over a horseshoe and a bar magnet. Notice that the lines of filings, which indicate the paths of these lines of force, lie side by side and run off parallel to each other to the right of the two north poles, but that they run from both north poles to the south pole in paths that are either straight or curved, depending upon their position. The mutual side push of lines

of magnetic force that pass through the air in the same direction, and also the fact that all lines of magnetic force are closed circuits under tension like elastic bands, will be found of especial importance in connection with electric currents.

328. Magnetic Field; Measurements. — A magnetic field is a space in which there are lines of magnetic force. The field usually considered is some limited *area*, always *perpendicular to the lines of force.*

If the like poles of two magnets of equal strength, when one centimeter apart, repel each other with a force of one dyne, each is called a *unit pole.* A magnetic field of *unit strength* is one where a unit pole would be acted upon with a force of one dyne. One line of force is called a *maxwell.* A magnetic field of unit intensity, that is, one having one line of force per square centimeter, is called a *gauss.*

A small bar of hardened steel will retain about 800 lines of force per square centimeter; that is, the intensity of its field is 800 gausses, and if the bar is 2 cm. wide and 1 cm. thick, there are 1600 maxwells in the field adjacent to the end of the magnet.

329. The Magnetic Condition of the Earth. — We have seen that the + pole of a magnet repels the + pole of a needle and attracts the − pole. We have also seen that the needle tends to set itself in the direction of the lines of force, and that a magnetic needle, suspended so as to swing freely, points with its *north* end toward the magnetic *north.* It is evident, then, that the earth acts as a great magnet, and that the pole toward which the north-seeking end of the needle points has the same kind of polarity as the − or south end of a bar magnet. The fact that the north magnetic pole of the earth and the north pole of a magnetic needle

are of unlike signs has given rise to some difficulty in giving them names that are scientifically correct; but the name north for the + pole of the needle is generally adopted.

330. Inclination or Dip. — In Fig. 278 we see that in every position but one the needle *dips* toward one of the poles. In a similar way a needle that has been balanced horizontally on a pivot, and then magnetized, will not remain horizontal, but will dip toward the nearer pole of the earth. The *angle of dip*, that is, the angle the needle makes with a horizontal line, increases as the distance from the magnetic equator increases. At the magnetic equator there is no dip, while at the magnetic poles the needle will place itself in a vertical direction.

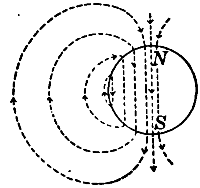


FIG. 282

The *true* pole is beneath the surface. The needle, except at the apparent pole itself, does not point directly toward the true pole, but instead lies tangent to a curved line of force, such as one of those shown in Fig. 282.

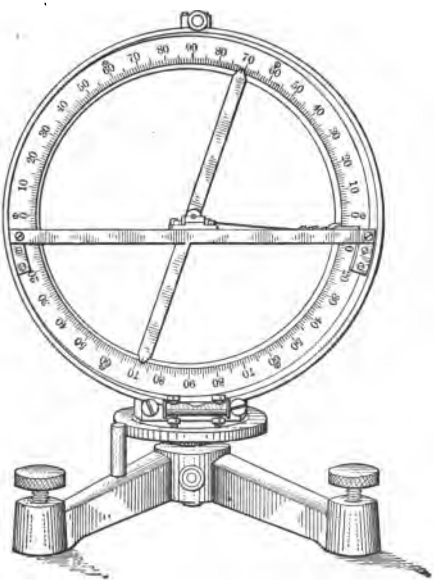


FIG. 283

331. The Dipping Needle.—Figure 283 shows a form of needle that is used to determine the dip. It consists of a magnetic

needle swinging on a horizontal axis which is in a direction perpendicular to the magnetic meridian. The needle itself swings in a vertical plane in the magnetic meridian. It is so balanced that it will come to rest in a horizontal position before being magnetized. After it is magnetized and placed in the magnetic meridian it will set itself in the line of dip.

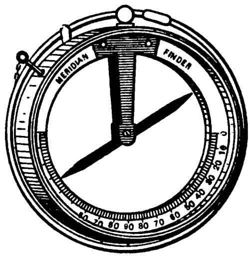


FIG. 284

The miner's dipping needle, Fig. 284, is a portable instrument of the same general type, that is used to detect the presence of magnetic ores.

332. Magnetic Declination. — At most places the magnetic needle does not point to the true north, but instead a little to the east or west of north. The chief reason for this is that the north pole of the earth and the magnetic north pole do not coincide. The magnetic north pole is about latitude 70° N. and longitude 96° W.

By reference to Fig. 285, it is readily seen that in the Eastern states, as in Maine, for example, the needle points to the west of the true north, while in California it points to the east of the true north. The angle between the direction of the needle at any place and the true meridian at that place is the *declination.* In some places the needle points to the true north; a line drawn through such places is called an *agonic line* or line of no declination. Figure 285 shows not only the agonic line in the United States, but also a line drawn through places where the declination is 1° west, another where the declination is 1° east, and so on.

333. Variation. — The angle of declination at any place changes from year to year by an amount which is not uni-

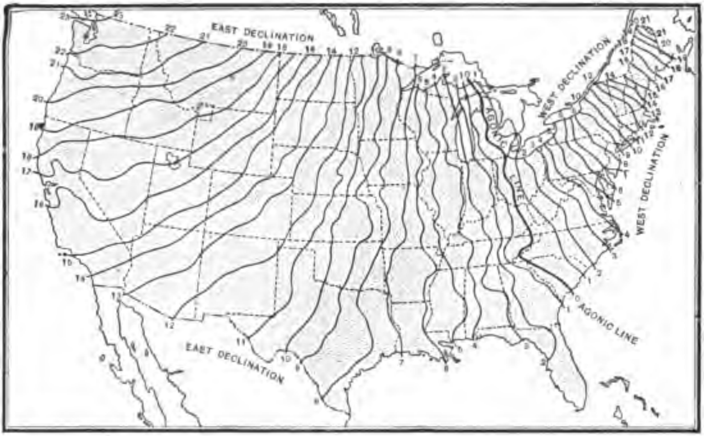


FIG. 285. — Lines of Equal Magnetic Declination

form, and which is called the *annual variation.* In surveying land it is very important that the amount of this variation should be known, and records of this change are made and preserved. By comparing these records, it is seen that the agonic line is moving westward, *i.e.*, the declination of places east of the line is increasing, and that of places west of the line is diminishing. The annual change at Philadelphia is about 4 minutes.

334. Magnetic Survey of the Ocean. — Since the course of a ship at sea is mainly dependent upon the readings of the compass needle, it is of especial importance that the magnetic dip, declination, and variation over the surface of the oceans should be accurately known. For the purpose of determining these values experimentally, the Department of Terrestrial Magnetism of the Carnegie Institution at Washington, D. C., built, in 1909, a remarkable sailing ship, the *Carnegie.*

Almost no iron or other magnetic material was used in this ship and the little that was used was placed so far from the

Fig. 286. — The Non-Magnetic Ship *Carnegie*

Fig. 287

Fig. 288

magnetic instruments that it had no disturbing effect upon them. Even the auxiliary gasoline engine is almost entirely of bronze. Because of this non-magnetic construction the *Carnegie* has been able to correct errors of from one to fifteen degrees in the magnetic charts used by mariners.

In five cruises nearly 200,000 nautical miles were covered, observations being taken every 100 or 150 miles. In October, 1919, the *Carnegie* started on her sixth voyage to extend over a period of more than two years, gathering data for the correction of magnetic variation charts.

Figure 287 shows the method of making observations; the most delicate instruments are permanently mounted and placed inside the dome. At the left of the dome is a gimbal stand, shown on a larger scale, with a sea dip circle mounted upon it, in Fig. 288.

335. Magnetic Induction. — We have seen that when a piece of soft iron is put in contact with a bar magnet, it becomes a magnet itself and will attract iron. When a magnet is dipped in iron filings or nails and lifts a number of them attached to one another, it is because each has become a distinct magnet. This influence of a magnet over pieces of iron or steel, by which they are made magnets, is called *magnetic induction*, and extends to a considerable distance from the magnet.

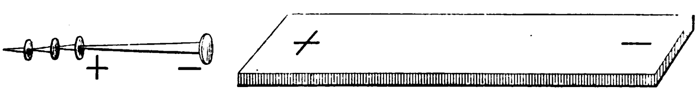


FIG. 289

Demonstration. — Place a bar magnet upon a table, and at one end, in line with it and about an inch away, put a large nail, as in Fig. 289. Bring smaller nails near the end of the large one, and observe that it attracts them. Test the end of the nail with the magnetized sewing needle, to find which kind of polarity it has.

This property possessed by a magnet — of inducing polarity in magnetic substances that are near it — is the basis of a great many magnetic phenomena. By the application of this principle, and that of the mutual action of magnets, we see why a magnet attracts ordinary pieces of iron — an iron ball, for instance.

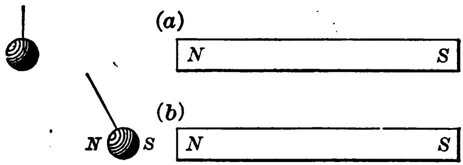


FIG. 290

Suppose the ball to be at a distance from the magnet, as in (*a*), Fig. 290. The ball is practically beyond the influence of the magnet and remains in a neutral condition. When, however, it is brought near the magnet, as in (*b*), induction takes place, and the ball becomes polarized, the side nearest the magnet being *S* and the other side *N*. Now between the *N* of the magnet and the *S* of the ball there is attraction, while between the *N* of the magnet and the *N* of the ball there is repulsion; but as the *S* of the ball is much nearer the *N* of the magnet than the *N* of the ball is, the attraction is much greater than the repulsion.

We see also why the iron filings in § 324 indicate the lines of force. Each particle of iron becomes a magnet by induction, and, like the magnetized needle, turns so that its two poles are in a line of force. Its poles also are attracted by the adjacent unlike poles of other particles, and thus the particles cling together, with their + poles turned toward the − end of the magnet, in lines of force.

336. The Inductive Action of the Earth can be shown most strikingly as follows:

Demonstration. — Select a soft iron bar about an inch in diameter and three or four feet long. Holding it horizontally in an east and west line, present its ends successively to the *N* and *S* ends of

a magnetic needle. Both ends will attract each end of the needle, showing that the bar is not polarized. Next hold it in the line of dip, with the lower end at the side of the needle and near the north end. The needle will be repelled at once, showing that in this position the bar is polarized. Reverse the bar and make the same test with the needle, and the needle will show that the polarity of the bar is reversed. Bring the bar into the first horizontal position and again it will attract both ends of the needle, showing that it is not polarized. Place the bar again in the line of dip and give it one or two sharp blows with a hammer. Now place it in the first horizontal position; and on testing it with the needle it is found to be polarized. Hold it horizontally in an east and west line and give it a few sharp blows; and it will be found to be not polarized.

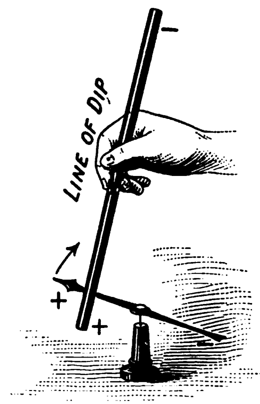


FIG. 291

With the magnetized sewing needle, test the steel or iron rods about the building for polarity. Most of them will be found polarized, especially if they have been in a vertical position. What is the polarity of the lower end of a vertical rod? Why?

337. Molecular Magnets. — If we consider the molecules of iron to be polarized, we can explain magnetism and magnetic induction as follows. A magnet is a piece of iron composed of molecular magnets which lie partly or wholly in a uniform direction. When a piece of iron is in a neutral condition, not polarized, the molecular magnets of which it is composed have no uniform direction, their positions being determined by the mutual action they have upon one another. When, however, a magnet is brought near, their mutual action is overpowered by the greater force of the magnet, they assume parallel directions, and the iron becomes a magnet.

338. The Effect of Breaking a Magnet.—Demonstration.— Magnetize a knitting needle. Determine its poles. File a notch at the middle and break it. Examine for polarity again, and compare with the polarity the needle had before breaking. Break one of these pieces in the middle and examine for polarity. On a drawing of the broken needle, mark the polarity of each end of each piece.

339. The Effect of Heating a Magnet. — If a sewing needle is magnetized and then heated to redness by being held in the flame of a Bunsen burner, it will be found, on testing it after cooling, that it has lost practically all its magnetism. This is probably due to the fact that, in heating, the vibrations of the molecules have increased in velocity until they no longer retain the positions which determine the polarity of the magnet. If the needle is heated red-hot from end to end, it cannot be picked up by a magnet, which shows that at that temperature steel is not a magnetic substance.

Questions

1. How do natural magnets become polarized?

2. Suppose a magnetic needle is attracted by a certain body; does this prove that the body is a magnetic substance? Does it prove that the body is polarized? What is the only action that proves polarity?

3. In what direction would the north end of a magnetic needle point at the northern end of Greenland?

4. What is meant by a uniform magnetic field? Give an example.

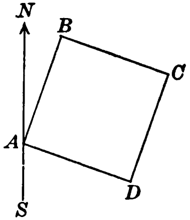


Fig. 292

5. The square piece of land shown in Fig. 292 was surveyed, starting from the point A. The line AB was found to have the direction N. 20° E. An old survey gave the direction of this line as N. 16° E. Show by a drawing the effect of running this out on the old directions, without allowing for a change in the declination.

6. Why are scissors, knives, and other steel tools often found to be magnets?

7. What position would a magnetic needle take if suspended, at the earth's surface, over the magnetic north pole? Over the magnetic south pole? At the magnetic equator?

8. Suppose you were to place a magnetic needle upon a thin cork disk on the surface of water in a wooden pail. Would it go toward the north? Explain. Make the experiment.

9. What is the effect of near-by iron ore, iron posts, steel wire fences, and the like, upon the surveyor's compass?

10. Why are the iron posts of a fence generally found to be magnetized? What is the polarity of their upper ends?

11. Show by a drawing the polarity of a magnet broken in two.

12. A test tube filled with iron filings can be magnetized by stroking with a bar magnet. Explain.

Problems

1. A bar magnet sends out 500 lines of force. How many dynes of attraction will there be between the + pole of this magnet and the − pole of a magnet of equal strength if they are 5 cm. apart?

2. It requires a pull of 12,000 dynes to keep the + pole of a magnet, having a strength of 200 lines of force, from going toward the pole of another magnet placed 2 cm. from the first. What was the polarity of the second magnet and what was its strength?

3. If two bar magnets placed end to end are repelled with a force of 1200 dynes when the poles are 20 cm.. apart, what will be the repulsion when they are 30 cm. apart, if we consider only the effect of the adjacent poles?

4. A cylindrical bar magnet is 2 cm. in diameter, and the strength of its field adjacent to the end of the magnet is 800 gausses. How many maxwells has it in this field?

5. A bar magnet is 2 cm. wide and 8 mm. thick. Its field adjacent to the end has 1200 maxwells. What is the strength of the field in gausses?

CHAPTER IX

ELECTRICITY

I. STATIC ELECTRICITY

340. Electrification. — **Demonstrations.** — Hold a warm, dry glass rod over a handful of cork filings, pith balls, bits of paper, etc., and the rod will not affect them. Rub the rod briskly a few times with a piece of silk or flannel, and the light bodies will begin at once to fly to the rod, will remain there for an instant, and will then fly back to the table.

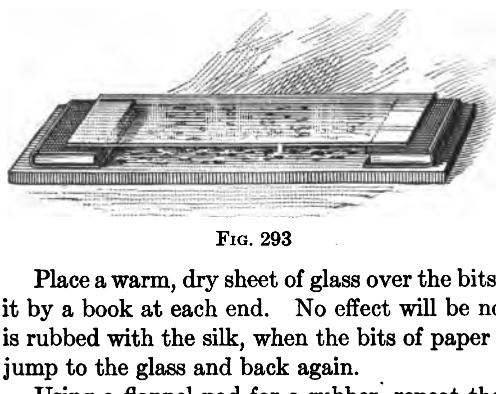


Fig. 293

Place a warm, dry sheet of glass over the bits of paper, supporting it by a book at each end. No effect will be noticed until the glass is rubbed with the silk, when the bits of paper will at once begin to jump to the glass and back again.

Using a flannel pad for a rubber, repeat the first demonstration with (1) a stick of sealing wax, (2) a rod of ebonite, and (3) a hard rubber comb.

The above demonstrations show that when glass is rubbed with silk, or sealing wax with flannel, there is imparted the property of attracting light bodies. The first record of such a phenomenon was made by the Greeks about 600 B.C. Because they noticed it in amber, which they called *elektron,* the name *electricity* has been given to the cause of these

phenomena, and a body that is capable of attracting others in this way is said to be *electrified*.

Demonstration. — Make a wire stirrup, as in Fig. 294, and suspend in it a wooden rod two or three feet long. Suspend this by a silk thread from a support and present, near one end, an electrified glass rod. The wooden rod will be at once attracted. Take out the wooden rod, suspend the glass rod, and present the end of the wooden rod; and now the glass rod moves. Suspend both rods, and they move toward each other until they touch.

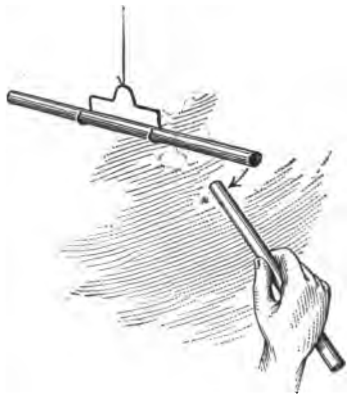


Fig. 294

This shows that the action that takes place between an electrified and an unelectrified body is *mutual*.

341. Two Kinds of Electrification. — We have seen that the glass rod, the sealing wax, and the ebonite rod all attract other bodies when electrified. Their action upon one another may be seen in the following:

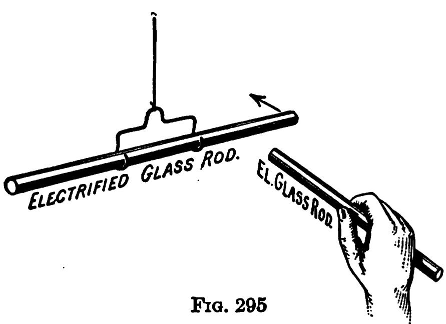


Fig. 295

Demonstration. — Electrify a glass rod and suspend it in the wire stirrup. Bring a wooden rod near it, and it will be attracted. Bring an electrified ebonite rod near it, and it will be attracted more than before. Now electrify a second glass rod and bring it near the end of the suspended rod, and repulsion takes place. Suspend

the electrified sealing wax in the stirrup and hold near it a second electrified stick of sealing wax, and repulsion takes place. Hold near it an electrified glass rod, and it is attracted. Hold near it an electrified ebonite rod, and it is repelled.

We find that the electrified glass rod and sealing wax have apparently the same effect upon an unelectrified body, but act differently upon one that is electrified. When this difference was first observed, the kind of electrification produced on a glass rod by rubbing with silk was called *vitreous* electricity, and that produced on sealing wax by rubbing it with flannel, *resinous* electricity. These are now called *positive* or + and *negative* or −, respectively. For the sake of convenience, these states of electrification will be spoken of as positive and negative electricity.

342. Action of Electrified Bodies upon Each Other. — Experiment has established the following general law concerning electrified bodies:

Bodies charged with like electricities repel each other, and those charged with unlike electricities attract each other.

Compare this with the first law of magnetism (§ 322).

Demonstration. — Cut out a number of pith balls with a penknife and roll them in the hands. Use the pith of corn, elder, or, better still, burdock. Suspend one of them from a bent glass rod by a fine silk thread. Electrify a straight glass rod and bring it near the ball, which will at once be attracted, cling to the rod for an instant, and then fly away charged with a + charge. Rub different bodies, such as a dry paper, a rubber comb, etc., first with silk and then with flannel. How are those charged that repel the ball? If a body attracts a charged pith ball, is it a proof that the body is charged?

343. Measure of Electrical Attraction and Repulsion. — If two minute bodies with equal charges of like electricities

when one centimeter apart in air, repel each other with a force of one dyne, each charge of electricity is called a *unit charge.* If one of these unit charges remained the same, the other would need to be increased to 10 units in order to increase the force of repulsion to 10 dynes. It is found that the force of electrical repulsion or attraction between any two small electrified bodies varies directly as the product of the charges, and inversely as the square of the distance between their centers. Hence

$$f = \pm \frac{Qq}{d^2}, \tag{51}$$

in which f is the force in dynes, Q and q the electrical charges of the bodies, and d the distance between their centers in centimeters. By reference to the law of mutual action (§ 342) it will be seen that the + sign means repulsion and the − sign attraction.

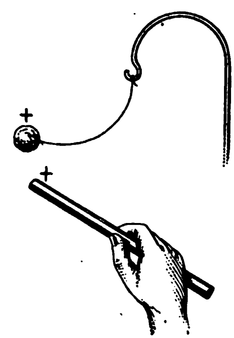


FIG. 296

344. Electroscopes.—Any instrument by means of which we can determine whether bodies are charged or not is an electroscope. A pith ball arranged as in Fig. 296 is a *pith-ball electroscope.* A common form is the *gold-leaf electroscope,* which consists of a glass jar, through the wooden stopper of which passes a brass rod terminating in a ball on the outside, and having two long, narrow leaves of some thin metal, as goldfoil, attached to the inner end. Whenever the ball is touched with a charged body the leaves receive a part of the same charge and diverge in accordance with the law of repulsion (§ 342), as shown in Fig. 297.

FIG. 297

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For convenience in using an electroscope, a *proof plane* may be made by cementing a thin metal disk to the end of a rubber penholder (Fig. 298). Put this plane in contact with any

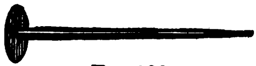


FIG. 298

charged body, remove it, and quickly *touch* the knob of an electroscope with it. Rub a glass rod with silk, touch it with the proof plane, and then bring the plane *near* the knob of the electroscope. If the leaves diverge still more, they show that the first body was charged *positively*. If the leaves fall together somewhat, it is probable that the body was charged negatively; but as *the repulsion of the leaves is the only sure test,* the proof plane must be charged negatively from sealing wax and again brought near the electroscope. If the leaves now diverge, the first body was charged negatively.

345. Conductors and Insulators. — **Demonstration.** — Wind one end of a copper wire a meter long around the knob of an electroscope, and attach a brass ball to the other end. Rest it on a glass support. Charge the proof plane from a charged body and touch the ball with it. The leaves of the electroscope will instantly diverge. Discharge the electroscope by touching it with the finger. Replace the wire by a silk thread, and no effect will be seen when the ball is charged. Replace the silk thread by a damp cotton thread, and the leaves will diverge gradually when the ball is charged.

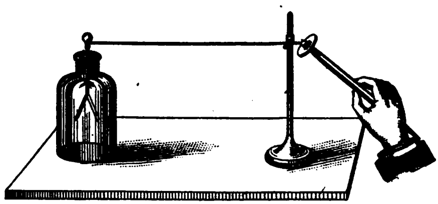


FIG. 299

Bodies like the wire, which carry electrical charges readily, are called *conductors;* while those like silk, which carry them

with difficulty, are called *insulators, nonconductors,* or *dielectrics.* There are no substances that are perfect conductors, neither are there any that are perfect insulators; but the following table gives what are usually classed as conductors and insulators, all arranged in the order of their conductivity.

Conductors		Insulators	
Metals,	Animals,	Dry Wood,	Glass,
Graphite,	Linen,	Dry Air,	Ebonite,
Acids,	Cotton	Paper,	Shellac.
Salt Water,		Silk,	

The conductivity of bodies depends upon their physical condition, temperature and moisture having a decided effect. Glass becomes a conductor at 200° C. Air under normal pressure is a good insulator, rarefied air is a poor one. Pure water is a very poor conductor, but is rendered a good conductor by the addition of a little salt or a few drops of acid. Whether bodies are conductors or not also depends upon the character of the electrical charge. A single layer of cotton is insulation between two wires carrying the current for an electric bell, but is no protection whatever against the sparks from a charged glass rod.

346. Friction Develops Both Kinds of Electricity.— Demonstration. — Rub a glass rod and an ebonite rod together, much as a mower whets his scythe. Test each by bringing it near the knob of an electroscope. The glass will be found to be charged positively and the ebonite will show an equal negative charge.

Tests carefully made by rubbing various substances together show not only that both kinds of electricity are produced, but also that the opposite charges generated are equal in amount. For instance, the + charge generated upon a glass rod is the same in quantity as the − charge generated upon the silk by which it is rubbed.

347. Can Conductors be Electrified by Friction? — If a brass tube is rubbed with either silk or flannel and then tested with an electroscope, no evidence of a charge will be found. This, however, is not a proof that no charge is generated; for any charge would be carried away by the body of the experimenter as fast as generated, since both the rod and the body are conductors.

Demonstration. — Flip a silk handkerchief against the knob of an electroscope and the leaves will be found to separate. The glass body of the electroscope could not carry away the charge generated by the friction of the silk on the brass ball. Determine whether the charge is positive or negative.

Rub a glass tube an inch or more in diameter with a silk pad. Present the knuckle to a point on the side, and take off a spark. Do this at various points along the tube. Since the glass is a nonconductor you discharge only a small area each time.

If unlike substances are pressed together and then rapidly separated, they will become oppositely charged. This is seen in the fact that sparks can be drawn from a leather belt in running machinery, especially in dry weather.

348. Distribution of Electricity over a Conductor. — If a metal sphere is placed upon an insulating support, such as a glass rod, and charged with a certain quantity of electricity, a proof plane placed upon any part of its surface will carry away the same charge, as may be found by tests with an electroscope (the leaves diverging as much from one charge as from another). But if an equal charge is given to an insulated metal cylinder with rounded ends,

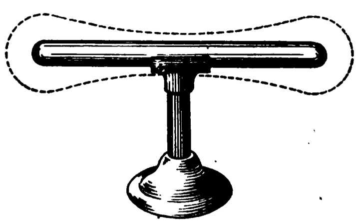


Fig. 300

the proof plane will carry a much greater charge away from the ends than from any other part of the surface. The comparative *density of charge*, or *quantity of charge per unit area*, is represented by the distance of the dotted line from the surface in Fig. 300. From this it appears that the density of charge is greater at the projecting parts of an insulated conductor.

FIG. 301

Demonstration. — Support a short metal cylinder upon an insulating stand. Fasten a wire 3 in. long vertically into the top of the cylinder. From the top of this wire suspend two pith balls by linen threads. Suspend two others from the inside of the cylinder. Charge the cylinder with the charge from a glass rod; the outer pair of balls will fly apart, while the inner ones will remain undisturbed.

From this we learn that *on an insulated conductor the electrical charge is located on the outside.* This location is caused by the mutual repulsion of like charges. It follows that, with the same charge, as the outside surface increases the surface density diminishes.

349. The Action of Points. — **Demonstration.** — Fix a pin, at its middle, to the end of a stick of sealing wax, which serves as an insulator. Charge an electroscope until the leaves are widely separated. Place the head of the pin against the knob, and observe that the leaves gradually fall together. Hold a pin in the hand and bring its point near the knob of a charged electroscope. What happens?

If the experiment with pin and sealing wax is made upon a body with a much greater charge than the electroscope, a decided current of air can be felt in front of the point. The density of the charge at the point electrifies the air particles, which, by the law of repulsion, are at once driven off. As each particle takes its own charge away, it follows that a

body with pointed surfaces cannot be kept charged, however good the insulation.

350. Electrical Potential. — **Demonstration.** — Charge two insulated conductors — tin cans upon glass tumblers will do — with the glass rod, and connect one of them with a gold-leaf electroscope by means of a piece of wire provided with an insulating handle. Notice the extent to which the leaves separate. Remove the wire from the body and discharge the electroscope. Connect the electroscope with the second body, and notice the divergence of the leaves. Now connect the two charged bodies by a conductor and notice that if the divergence of the leaves of the electroscope was less when connected with the second body than when connected with the first, they will now diverge more widely than before when connected with the second, and *vice versa.* On connecting the electroscope with the first body it will be found to give the same divergence as the second.

From this demonstration we conclude that there has been a flow of electricity from the body giving the greater divergence of the gold leaves to the other. This condition of electrified bodies which sets up an *electric current* in a conductor which connects the two bodies is the *difference of potential* or the P. D. of the bodies.

If the electrified body connected with the electroscope is now connected with the earth, the leaves will at once fall together, showing that the electroscope is discharged. The quantity of electricity in the body is so small that it does not, on being connected with the earth, change the condition of the earth in any perceptible degree. The earth is — for the sake of reference — assumed as the *zero of potential,* bodies positively charged being considered at a higher potential than the earth, while those negatively charged are at a lower potential than the earth. If the difference of potential between two bodies is kept constant, the current passing

in the conductor that joins them will be a *continuous current.* If the P. D. is not maintained, the current will be only *momentary.*

Potential is analogous to water pressure, and the current to the flow of water that takes place in a pipe connecting two bodies of water at different levels. The position of the water of a water tank with respect to the surface of the earth would be positive: the water would run from the tank to the earth. The position of the water in a well would be negative: the water would flow from the surface into the well.

351. Capacity. — If two insulated conductors, of the same shape but of different sizes, are charged to the same potential, it will be found that the larger one has a greater charge than the other. This means that there is a difference in their *electrical capacity.* The capacity of a conductor is the ratio of its quantity of charge to its potential; that is,

$$C = \frac{Q}{V}, \tag{52}$$

in which C = capacity, Q = number of units of electrification, and V = number of units of potential.

The word *capacity* as used in electricity has a meaning different from that usually given to it. We say that the capacity of a gallon jug is 4 quarts, meaning *when it is full.* From Formula 52, we see that the capacity of a conductor is equal numerically to the quantity of electricity on it *when its potential is* 1 *unit.* The quantity that a gallon jug can hold is never greater than its capacity — 4 quarts; but the number of units of charge that can be given to an insulated conductor may be many times its capacity, in which case its potential will be many times 1 unit. Since electricity

in its static condition is on the outside of bodies, a wooden ball covered with metal foil has the same capacity as a solid metal ball of the same size.

352. Induction. — **Demonstration.** — Bring an electrified glass rod near the knob of an electroscope, and the leaves will begin to diverge when the rod is a foot or more away. Bring it nearer, and the divergence is greater. Remove the rod, and the leaves fall together.

We learn from this that the influence of the charged rod extends to some distance through the air. This action of a charged body upon another body in the *electrical field* which surrounds it, is called *electrostatic induction.*

353. To Charge a Body by Induction. — In the preceding demonstration we notice that the electroscope remains charged only so long as the *inducing body* is near it. It is possible, however, to charge the electroscope permanently, as follows:

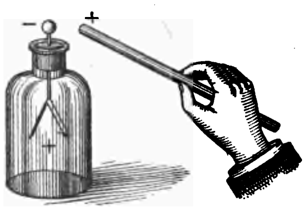


FIG. 302

Demonstration. — Bring the glass rod near the knob as before, and when the leaves have separated, touch the knob with the finger. The leaves instantly fall together. Now remove first the finger and then the rod, and the leaves again diverge, showing that the electroscope has received a permanent charge.

To explain this action we must remember that *like electricities repel, and unlike electricities attract each other.* When the electrified rod is brought near the knob, the + of the rod separates the electricities in the knob, wire, and leaves of the electroscope, driving the like kind, +, to the leaves, and holding the unlike kind, −, near to itself in the knob

as in Fig. 302. When the knob is touched it is put in contact with the earth, and the + electricity, repelled by the + of the rod, escapes, while the − is held *bound*. Figure 303 shows this condition. Figure 304 shows the condition when the contact with the earth is broken and then the glass rod is removed. The − electricity is no longer *bound*, but *free*, and so passes partly from the knob into the wire and leaves, which diverge less than before, but with a charge of − electricity.

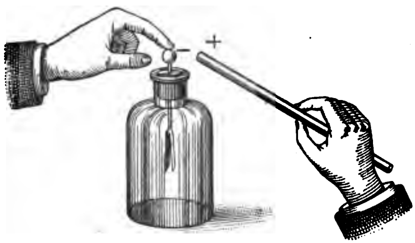


FIG. 303

FIG. 304

From this we see that a body can be *charged by induction,* if only some way is provided by which to carry off the electricity that is repelled by the inducing body.

The inductive action of a charged body is well shown in an experiment first made by Faraday, called the *ice-pail experiment* because he used ice pails in making it:

Demonstration. — Place a thin metallic vessel, like a tin can, upon an insulating stand and connect it by a wire with the knob of an electroscope. Suspend a positively charged metal ball by a silk thread and lower it within the can; the leaves at once diverge. Remove the ball, and they fall together. Lower the ball again, and they diverge. Touch the can, and they fall. Remove the finger and then the charged ball and the leaves separate, charged with negative electricity. Explain.

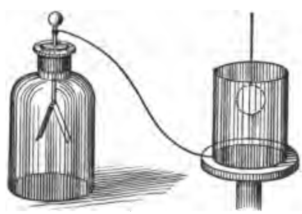


FIG. 305

Discharge the electroscope and again lower the ball. Observe the amount of divergence of the leaves. Let the ball touch the inside of the can. Notice that the divergence of the leaves is not changed. Remove the ball, and the leaves will still be separated, charged with positive electricity. Explain.

A thorough study and understanding of the above experiment will give the student a correct idea of the phenomena of induction.

The attraction of an unelectrified body by an electrified one is the direct result of induction. The positive electricity on a charged glass rod repels the positive electricity of a pith ball and attracts the negative. Since the distance between the positive charge on the pith ball and the glass rod is greater than the distance between the negative charge and the rod, the repulsion is less than the attraction, and the pith ball is attracted.

354. Specific Inductive Capacity. — The quantity of electricity that can be given to a body by induction depends upon the extent of its surface, the distance between it and the inducing body, and the character of the dielectric that separates them. The property that dielectrics have of transmitting electrical induction is called their *specific inductive capacity.* The specific inductive capacity of air is taken as unity, and that of a few other substances is shown in the following table:

Air	1.00	Shellac	2.75
Paraffin	2.00	Ebonite	3.40
India Rubber	2.25	Glass	6.25

Demonstration. — Suspend a charged ball at a fixed distance above the knob of an electroscope and observe the divergence of the leaves. Introduce between the ball and the knob a cake of paraffin, or a plate of glass, first making sure that it is not electrified, and notice the change in the divergence of the leaves.

355. The Electrophorus is a simple and inexpensive instrument for generating an electric charge, and is more convenient than the glass rod and silk pad. It consists of a glass plate resting upon a metal plate, as in the lower part of Fig. 306, and of a disk of brass or other metal with an insulating handle *H*. To generate a charge upon the glass plate it is rubbed with silk; this gives it a positive charge. The brass plate is then placed upon the glass; since the surface of the glass is uneven, there is a thin layer of air between them except at a few points of contact, and hence the disk becomes charged by induction as shown in (*a*), Fig. 307. The upper surface of the disk is now touched with the finger, and the free positive charge escapes, as in (*b*). When the

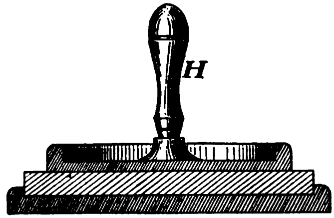


Fig. 306. — Electrophorus

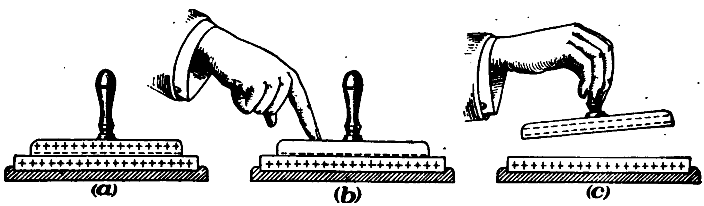


Fig. 307. — Operation of the Electrophorus

disk is lifted by the insulating handle, the negative charge, which was held bound by the positive of the glass, becomes distributed over the entire surface, as in (*c*), and may be taken off as a spark. The disk may then be at once replaced on the glass, touched with the finger, and removed, and another spark of practically equal length obtained.

When the disk is lifted, work is done not only against

gravity but also against the attraction between the negative charge on the disk and the positive on the plate. The energy of the discharge that can be taken from the electrophorus is given to it by the work that is done against this electrical attraction, and by the law of conservation of energy the amount of this energy is equivalent to the work done.

If a positive charge is desired instead of a negative, the glass plate is replaced by one of ebonite or wax.

356. Condensers. — The principle of induction is used to give to a body a much greater charge than it would otherwise receive.

Demonstration. — Cut out a sheet of tin foil six inches square and place it in the middle of a pane of glass a foot square. Count the number of sparks that you can make pass from the electrophorus disk to the square of tin foil. Discharge the tin foil by touching it. Lift the glass plate from the table and place under it a second sheet of tin foil connected with the earth. Count the number of sparks that you can now make pass into the upper tin foil. Touch the lower tin foil with one hand, and the upper tin foil with the other. How does the spark differ from the ordinary?

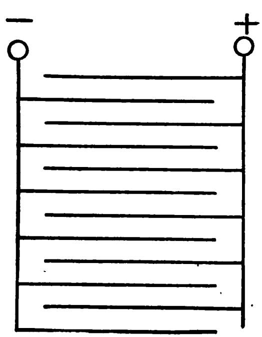


Fig. 308

The simple instrument used in the above demonstration contains all that is essential in a *condenser*, namely, *two conductors separated by a dielectric*. The reason for using a condenser is that we may increase the quantity of electricity without increasing the potential. *The quantity of electricity that can be stored on each conductor is directly proportional to its area and inversely proportional to the thickness of the dielectric between the conductors.* The reason for the

action of the condenser follows from § 353. A convenient form of condenser of large capacity can be made by arranging two sets of sheets of tin foil as in Fig. 308, and separating them by putting sheets of mica, or paper soaked in melted paraffin, between them.

357. The Leyden Jar is a convenient form of condenser. It consists of a glass jar with a wooden stopper, through which passes a brass rod terminating outside in a metal ball and inside in a chain touching the inner coating of the jar. The jar is coated both inside and outside, to about two thirds its height, with tin foil pasted on the glass. The jar should be made of thin glass, to give it greater capacity, but if the glass is too thin, it is liable to be pierced by a heavy charge.

FIG. 309. — Discharging a Leyden Jar

The Leyden jar is charged by holding it in the hand, or in some other way connecting the outer coating with the earth, and presenting the ball, connected with the inner coating, to the source of electricity. It is discharged by touching the outside coating with one end of a discharger and bringing the other end near the knob of the jar, when the discharge will take place in the form of a heavy spark, as in Fig. 309. The outer coating should be touched by the discharger first, or the heavy spark will tear off the tin-foil coating.

358. Seat of the Charge. — If the discharger is used again a short time after a jar has been discharged, a second and much fainter discharge takes place. This could not be the case if the charge were located in the conducting coatings, as they would be discharged at once.

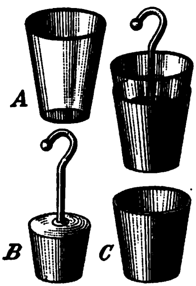


Fig. 310

Procure a *Leyden jar with movable coatings*, which consists of a cone-shaped glass jar, *A* in Fig. 310, having two conical tin coatings, one, *B*, fitting the inside, the other, *C*, the outside of the glass. Put the parts together and charge the jar. Remove the inner coating with a glass rod and bring it near an electroscope. It will be found to have no charge. Remove the outer coating and test in the same way. It has no charge. Now put the jar together again, and a spark can be taken from it by connecting the inner and outer coatings.

These results prove that the coatings act simply as a means for collecting the charge, and that the seat of the charge is in the glass. As the glass is a poor conductor, the charge does not all pass into the coatings at once, when the jar is discharged. This explains the second spark, which is called the *residual discharge*.

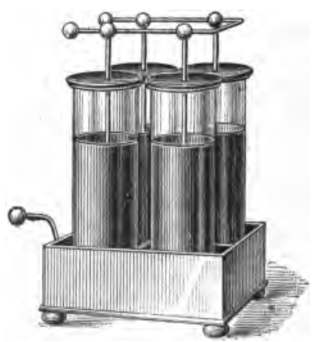


Fig. 311. — Leyden Jars

359. Battery of Leyden Jars. —The method usually employed to secure large capacity with Leyden jars is to connect the outer coatings of a number of jars to the earth or to one terminal of an electrical machine, and the inner coatings to the

other terminal. In this way the surface is increased, and a greater quantity of electricity can be stored. The spark from such a battery is much thicker than one of the same length from a single jar.

360. Electrical Machines; Frictional Machines. — In the early forms of electrical machines the charge was developed directly by friction. The most convenient of these was the *plate machine,* which consisted chiefly of a glass disk mounted upon an axis and turned by a handle, the charge being produced by the friction of fixed rubbing pads. On account of the friction, this machine required a great deal of energy to run it, and partly for this reason it has nearly gone out of use.

361. Induction Machines. — The simplest form of the induction machine is the electrophorus (§ 355). In fact, a

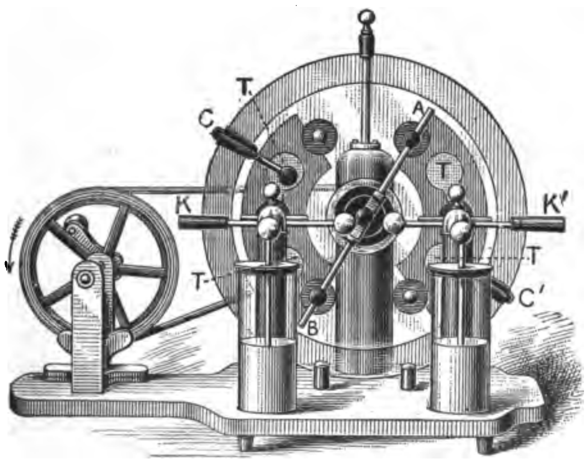


Fig. 312. — Toepler-Holtz Electrical Machine

large induction machine may be considered a *continuous electrophorus.* Many forms of induction machines are in

use. In the Toepler-Holtz machine there is a fixed glass disk called the *field plate*, having pasted upon the back side four tin-foil disks, T, connected two and two by strips of tin foil covered with large sectors of paper. These *inductors* correspond, one pair to the glass plate of an electrophorus (being charged positively), and the other to the ebonite plate of another electrophorus (charged negatively). In front of the field plate is a second glass disk, which rotates upon an axis. On the front face of this disk there are pasted, at equal intervals, six tin-foil disks, to the centers of which there are cemented metal buttons. These correspond to the brass disk of an electrophorus. A fixed rod, with a metal comb at each end, crosses diagonally from A to B in front of the movable plate, and fulfills the function of the finger that touches the electrophorus disk. The two kinds of electricity are taken off by collecting combs on opposite sides, connected with two rods which have at their outer ends insulating handles, K and K', and on the inner ends brass balls, the terminals between which the discharge takes place. A brighter spark may be obtained by connecting a Leyden jar to each terminal, as shown in the figure.

The machine is first charged by setting the rotating plate in motion and then sending a spark of + electricity from a charged glass rod to one of the inductors on the back of the stationary plate, for example, on the right-hand side in the figure. This induces a − charge in and near disk A on the rotating plate, and through the diagonally fixed rod a + charge is repelled to disk B. As the plate rotates, disk A is carried to the left, and the metal button on it is brought into contact with a small metal brush attached to C, an arm connected with the inductor on the left side of the field plate. A part of the − charge of disk A passes over to that inductor, the remainder is repelled by the − inductor into the collecting comb connected with K, and when this disk A reaches the position marked

B, it is charged positively by the direct influence of the left-hand inductor combined with the indirect influence of the other inductor, as explained at the beginning. Meanwhile the original disk B has given up part of its + charge to the right-hand inductor through C', and the rest to the collecting comb connected with K', and at position A is receiving a − charge by induction, in the same way that the disk at B is receiving a + charge.

The terminals should be put in contact until a hissing sound shows that the machine is highly charged. When they are separated, a series of sparks will pass from one terminal to the other. Examine the two sides of the machine with a pith-ball electroscope to see which is + and which −. Discharge it, start over again, using a spark from a stick of sealing wax to charge the first inductor, and examine with pith-ball electroscope as before.

362. The Spark. — A little study of the sparks that pass between the terminals will show that the polarity of the machine determines the appearance of the spark. The main spark is purple in color, and the ends differ according to their polarity, the negative end being a minute bright point, while the positive end is not so bright; the bright part, however, is longer, being about an eighth of an inch in an inch spark.

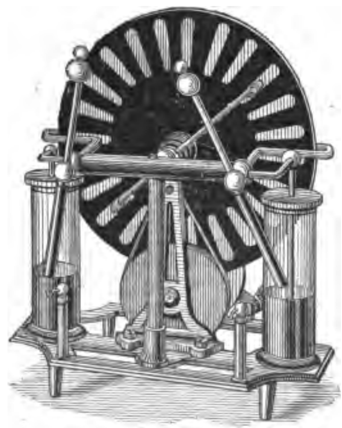


FIG. 313. — Wimshurst Machine

363. The Wimshurst Machine has two glass disks, both of which rotate, but in opposite directions. Tin-foil sectors are attached to the outside of each plate. For convenience in explaining the action of this machine, in Fig. 314 the glass disks are replaced by glass cylinders, one inside the

other, and shown in section. AA' and BB' are the cylinders, the sectors on AA' being on the outside, and those on BB' being on the inside, CC' and DD' are the diagonal rods, tipped with brushes; and EE' and FF' are the collecting brushes. Only the slightest difference of potential is needed to start the induction. Suppose the sectors near A to have a slight + charge. This will induce a − charge on C, while the repelled + will go to C'. The sectors that come in contact with the brushes on C and C' will receive slight charges which will in turn act inductively on the outer sectors; the rod DD' acting like the rod CC'. At the collecting brushes E and E' the − charge on each cylinder repels that on the other to E and E' and the terminal T'. In a similar way a + charge collects on T.

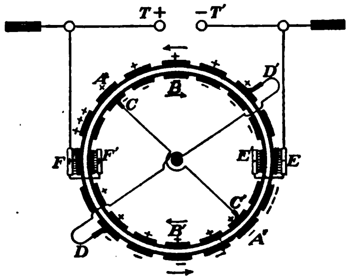


FIG. 314

364. The Effects of the Discharge from a Leyden jar or from an electrical machine, include (*a*) mechanical work, (*b*) heat, and (*c*) light.

365. Mechanical Effects. — Demonstrations. — Hold a thick card between the terminals of a Holtz or Wimshurst machine when it is connected with the condensers, and set the machine in action. A spark will pass, and since the card is a nonconductor, the spark will tear its way through.

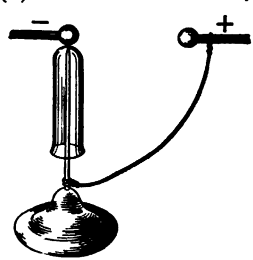


FIG. 315

Set a wire upright in a wooden base, and file its upper end to a point. Place over this wire a thin test tube, as in Fig. 315, and bring

one terminal of the machine directly over it. Connect the wire with the other terminal, and attach the Leyden jars. When the machine is put in operation, a spark will pass and pierce the tube. If the tube is a thick one, several sparks may go from point to knob over the surface of the glass before it is pierced.

Any nonconductor, if not too thick, can be pierced by the condenser spark between the terminals of the machine. Cardboard, books, seasoned wood, etc., should be tried. Try a metal plate also. Is it pierced? Explain.

366. Heat Effects. — The amount of current that passes when a charged body is discharged through a conductor is but small, and the heating of the conductor is consequently little. When the discharge takes place through a nonconductor, however, the effect is much greater. The spark itself is evidence of this, since in this case enough heat is given off to produce light. The spark is sometimes used to light the gas in buildings where the chandeliers cannot be readily reached.

Demonstration. — Bring a gas jet between the terminals of a machine. Operate the machine until the sparks pass, and then turn on the gas. It is lighted at once. Why?

367. Light Effects. — The light effects of the discharge can best be studied at night, though a room that can be made nearly dark with curtains will do. In the first place, the machine itself affords excellent illustrations of these effects. The shower of purple sparks that follow one another so rapidly that the images of six or eight are continually seen, — the sharp spark of the condenser discharge, which makes everything dazzlingly bright, and which takes place so quickly that the rapidly rotating wheel, as seen by its light, seems to stand still, — the cascade of minute sparks that

flows over the plate near the collecting combs, — and the glow of light that tips every point of the combs, — all are light effects of the most interesting kind.

Demonstration. — Cover one side of a dry white pine board with a heavy coat of shellac. Next place on this a layer of thin tin foil and cover this with shellac, rubbing it down fast to the board. Dry thoroughly and then with a sharp knife cut the tin foil into squares a quarter of an inch on a side. Connect the tin foil at the ends of the board with the terminals of the machine, and the discharge will be seen to pass the entire length of the tin foil, causing a spark at every place where the conductor has been cut.

Such boards can be made in any desired shape; they illustrate the fact that if a discharge takes place along a broken conductor a spark will occur at every gap.

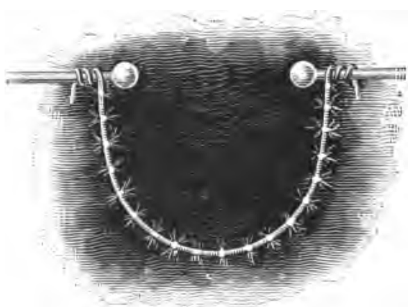


Fig. 316

Demonstration. — Get a piece of No. 30 magnet wire and with a knife or pair of cutting pliers cut the wire every half inch without cutting the insulation. Suspend this from the ends over the terminals of the machine, and when the machine is put in motion every break in the wire will furnish a bright spark. The insulation will hold the pieces of wire in place, and they can be made into many fanciful shapes.

Fig. 317. — Brush Discharge

368. The Brush Discharge is another very interesting light effect. It is obtained by drawing the terminals of a machine two or three inches apart. The distinct sparks will then cease and the discharge will take the form

of Fig. 317. Near the positive terminal the discharge is bright, like an ordinary spark, but about half an inch away it branches out and becomes a purple glow until the negative pole is reached, where there are a number of bright points.

369. The Discharge in Rarefied Gases. — The electric discharge that takes place in the air at ordinary pressure gives rise to a bright light and a sharp report. If the discharge takes place in a partial vacuum, however, the light is very much softened and the discharge is silent.

Demonstration. — Hold the bulb of an incandescent lamp between the terminals of a Holtz or Wimshurst machine, and set the machine in motion. The lamp will be filled with a pale glow, which will come and go in flashes as long as the machine is turned. The discharge in rarefied gases is studied further in § 445.

370. The Discharge of the Leyden Jar Oscillatory. — Experiments show that the discharge of a condenser is an oscillation, the charge going first in one direction and then in the other. This is analogous to what will take place in a U-tube, such as is shown in Fig. 318, if it is filled with water in the two arms to the points A and B. If now the clamp at C is suddenly opened, the water will flow from the left side to the right, and instead of stopping at the level line xy will pass on to D and E. The same thing now takes place in the opposite direction, and so continues alternating until the water finally comes to rest at the level xy.

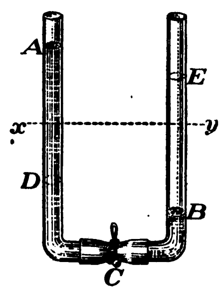


FIG. 318

371. Atmospheric Electricity. — No one who has observed both the discharge of frictional electricity and lightning has failed to notice the similarity between them. Their identity

was proved by Franklin in 1752. His method of proof was one that would not be followed at the present time on account of the danger to the experimenter. What he did was to fly a

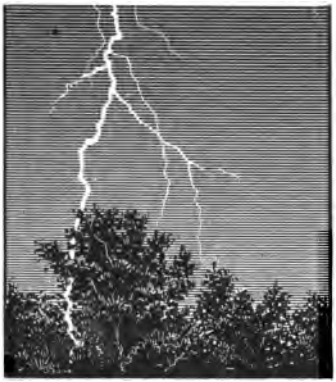


Fig. 319. — Lightning

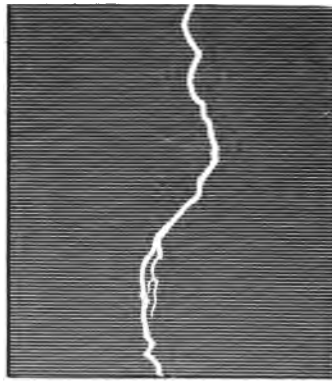


Fig. 320. — Condenser Discharge

kite in the face of an advancing thunderstorm. A pointed wire was fastened to the top of the kite, and a short strip of silk was tied to the kite string. At the junction between the kite string and the silk strip a door key was tied. As long as the kite string was dry, no results were obtained, but as soon as it became wet with the rain (making it a better conductor), Franklin found it possible to draw sparks from the key by bringing his finger near it.

372. How Clouds become Charged. — Experiment has proved that if water is allowed to fall upon a rising current of air that is rapid enough to break it into drops, the drops become positively and the air negatively charged. It is well known that the formation of the cumulus cloud, called a thunder head, is caused by an uprush of warm, vapor-laden air into the cooler upper atmosphere. This

gives rise to a turbulent condition in the clouds, which seem to be "boiling," or rolling over and through each other, and sets up such a condition that the raindrops formed become electrically charged.

373. Lightning. — This high potential positive charge in the clouds induces a negative charge in the earth beneath, and as soon as the difference of potential between them becomes great enough, the spark, or *lightning* flash, breaks through the air, taking the path of least resistance, and generally striking a tree or some other high object. It happens sometimes that the negative charge is induced in a neighboring cloud, and then we see a beautiful display of lightning between the two oppositely charged clouds, and no damage is done by the discharge.

During the hot weather of summer there are few nights in which one cannot observe the reflection, from clouds near the horizon or from the air, of flashes of lightning in a distant storm. The storm may be fifty miles away and entirely below the horizon. This form is often erroneously called *heat lightning*.

374. Thunder. — In the case of a lightning flash the air is the dielectric which is broken through, and since the velocity of the discharge is very great, it is probable that a compression wave is set up in the air like that which is set up by a flying cannon ball and that this wave striking the ear produces the sound of the thunder. Other causes may help to produce it, such as the restoring to a condition of rest of the air that has been broken through by the flash, or the formation of steam from the moisture in the air, caused by the heat of the discharge. To a person who is near the flash the sound is that of a crash, but to one at some distance the direct report is

mingled with its echo from the clouds and the earth, producing the deep, rolling sound that we call *thunder*.

375. Lightning Rods. — Franklin's invention of the lightning rod was the natural outcome of his experiment with the kite. The function of the lightning rod is not to attract a stroke of lightning, but to reduce the potential difference between the clouds and the earth by a quiet discharge. To secure this, the rod must be well supplied with points at the top and must make a permanent connection with the damp earth below. Copper sheets fastened to the lower end of the rod make a good earth connection. If a full lightning discharge from the clouds to the earth should strike a lightning rod, the building might be damaged, just as Dr. Franklin might have been killed had lightning struck his kite.

376. The Aurora Borealis and *Northern Lights* are names given to beautiful light phenomena in the northern part of the northern hemisphere. The general explanation is that the aurora is an electrical discharge taking place in the upper regions of the air, where its density is much less than at the surface of the earth. The position of the aurora and the direction of its streamers seem to be definitely connected with the magnetic condition of the earth, the streamers centering at the north magnetic pole, as reported by Arctic explorers.

Questions

1. In sharpening a pencil, the shavings sometimes cling to the knife or the pencil. Why?

2. How would you determine the kind of electricity with which a body is charged?

3. Why does a charge go to the outside of an insulated tin can?

4. What will be the force and character of the mutual action between a + charge of 10 units and a − charge of 6 units, if the two are 2 cm. apart? What between a − charge of 20 units and a − charge of 10 units 3 cm. apart?

5. If one end of a wooden stick that is supported on a glass stand is brought near the knob of an electroscope, and a charged glass rod is brought near the other end of the stick, the leaves will gradually separate. Why?

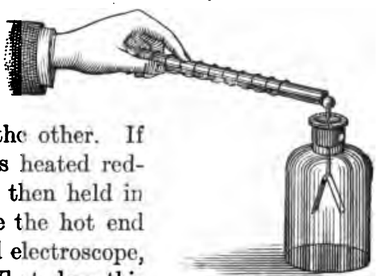


FIG. 321

6. Figure 321 shows a glass tube with a wire wound spirally around it from one end to within three inches of the other. If the unwound end of the tube is heated red-hot, and the tube and wire are then held in the hand by the other end, while the hot end is held to the knob of a charged electroscope, the leaves will go together. What does this prove?

7. What would be the effect of running a metal pin, connected with the earth, through the glass plate of an electrophorus, until it almost or quite touches the disk when it is resting on the glass? Explain.

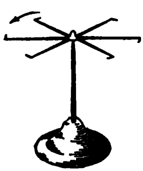


FIG. 322

8. Explain why the electric whirl shown in Fig. 322 will rotate when put in contact with one side of an electric machine. Does it make any difference whether the whirl is connected with the + side of the machine or with the − side? Explain.

9. Why is the spark thicker when Leyden jars are used with the machine than when they are not?

10. What are the essentials of a condenser? What might result from making a Leyden jar from a very thin beaker?

11. Can you charge a Leyden jar heavily if it stands on a glass plate? Why?

12. A pith ball is placed upon a metal plate connected with the earth. A similar plate connected with the positive pole of an electric machine is suspended over it. The pith ball rapidly passes from one plate to the other. Explain.

II. CURRENT ELECTRICITY

377. The Electric Current. — The discharge of electricity that takes place when a spark passes between the coatings of a Leyden jar is an electric current. The time during which the current passes, however, is very short. *Continuous* currents are produced whenever a conductor connects two points at which a difference of potential is constantly maintained.

Demonstrations. — Make a solution of sulphuric acid (H_2SO_4) by pouring slowly 5 c.c. of the acid into 100 c.c. of water. Place a strip of copper and a strip of zinc in the jar containing the dilute acid. As long as the plates are separated, the only action that takes place is the formation of a few hydrogen bubbles on the surface of the zinc plate. But as soon as the two plates are brought in contact — which may be done by bending the plate as in Fig. 323 — there is a rapid giving off of hydrogen from the surface of the copper plate.

FIG. 323

Solder a copper wire to a thin sheet of copper, and attach a binding post to a zinc battery plate. Repeat the preceding demonstration with these plates and observe that the change in the formation of gas takes place just when the copper wire is attached to the binding post on the zinc plate. Disconnect, bring the wire over and parallel to a magnetic needle, and the needle will be deflected as soon as the wire is again touched to the binding post. The needle swings back to its original position as soon as the wire is disconnected, or when either plate is lifted out of the solution.

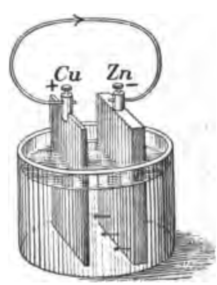


FIG. 324

In the last demonstration the deflection of the needle is caused by the passage of an electric current. As soon as

the plates are joined by a wire, as in Fig. 324, the current passes in the external circuit from the copper to the zinc, while the difference of potential is maintained by continued chemical action in the cell.

378. The Poles of a Cell. — The apparatus just described constitutes a *voltaic cell*, or *galvanic cell.* The terminals of the plates to which the conductor is attached are called the *poles* of the cell, the zinc being the negative and the copper the positive pole. When the poles are joined by a conductor, the cell is on a *closed circuit;* when they are not, it is on an *open circuit.*

379. Chemical Action in the Cell. — The phenomena taking place in the cell are practically as follows: When the zinc goes into solution with the H_2SO_4, it does so in the form of *ions, i.e.,* atoms or groups of atoms, charged with positive electricity. These zinc ions leave the zinc plate negatively charged by the separation, and displace positive hydrogen ions in the solution H_2SO_4, forming zinc sulphate ($ZnSO_4$). The positive ions of displaced hydrogen, repelled by the positive ions of zinc in the solution, move to the copper plate, and, discharging their positive electricity upon it, pass off in the form of hydrogen gas. In chemical symbols the action is as follows:

$$Zn + H_2SO_4 = ZnSO_4 + H_2.$$

The migration, as it is called, of positive H ions toward the copper, and of negative SO_4 ions toward the zinc, depends upon the dissociation of some of the molecules of the H_2SO_4 into hydrogen, HH, and sulphion, SO_4, in the solution.

If the cell is on an open circuit, this action diminishes as the charges on the plates increase, and finally stops,

having produced a difference of potential between the zinc and copper plates that constitutes the *electro-motive force* of the cell.

The action stops when the attraction of − SO_4 ions for + zinc ions is counterbalanced by the attraction of the − zinc plate for the + zinc ions; and when the repulsion of the + zinc ions against the + hydrogen ions is counterbalanced by that of the + copper plate. If the cell is on a closed circuit, the positive charge on the copper plate discharges through the circuit and neutralizes the negative charge on the zinc plate, producing an electric current, and the action is continuous.

380. Local Action; Amalgamating the Zinc. — When a strip of zinc is placed in the acid, hydrogen bubbles are given off from its surface. This is due to the setting up of an electric current between impurities in the zinc and the zinc itself through the acid and is called *local action.* The existence of these impurities can be proved by leaving the zinc in the acid for five minutes, when it will be found covered with a black deposit that can be wiped off.

If a particle of carbon is at A (Fig. 325), a local current will be set up between it and the zinc, and as a result hydrogen will be set free. In order to prevent this action, which reduces the surface of the plate for the main current, the zinc is cleaned by dipping it in dilute sulphuric acid and then rubbing with mercury. This has the property of dissolving the zinc and forming a covering over the particles of carbon as shown at B in Fig. 325, thus preventing the carbon from coming in contact with the acid.

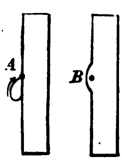


Fig. 325

381. Polarization of the Cell. — When the circuit is made in the simple voltaic cell, it is noticed that, while bubbles of hydrogen rise to the surface of the liquid, the copper

plate is kept pretty nearly covered by them all the time. This causes what is known as *polarization* of the cell and has two effects: (1) it reduces the amount of surface of the plate exposed to the liquid, and (2) it reduces the difference of potential between the plates. Both of these results tend to lessen the amount of current that can be sent by the cell. The usual way in which this difficulty is overcome is by the use of a kind of liquid that will oxidize the hydrogen before it is deposited on the plate.

382. Different Forms of Cells. — Many different substances may be used in place of the copper, zinc, and sulphuric acid in the simple cell described above. It is always necessary, however, that the acid or salt in the solution shall act more strongly on one of the plates than on the other. There are many different forms of cells in use, but most of them have zinc as the metal to be acted upon. These may be grouped in classes, of which the following are types.

383. The Daniell Cell. — This is an early form of cell in which a zinc bar is placed in a porous cup containing dilute sulphuric acid, while a copper cylinder and a solution of copper sulphate are in a larger glass jar holding the porous cup. As the sulphuric acid acts upon the zinc, zinc sulphate is formed within the porous cup, while hydrogen is displaced from the sulphuric acid and passes through the porous cup. This hydrogen displaces the copper from the copper sulphate

FIG. 326

and the copper is deposited on the copper plate. In order to keep up the strength of the copper sulphate solution,

copper sulphate crystals are placed in a cup attached to the cylinder in the outer jar.

384. The Gravity Cell. — In the crowfoot type of gravity cell a star-shaped group of copper sheets, surrounded by crystals of copper sulphate ($CuSO_4$), is placed in the bottom of a glass jar. Water to which a few drops of sulphuric acid have been added is poured in until the cell is nearly full, and then a zinc plate or "crowfoot" is hung from the upper edge of the jar.

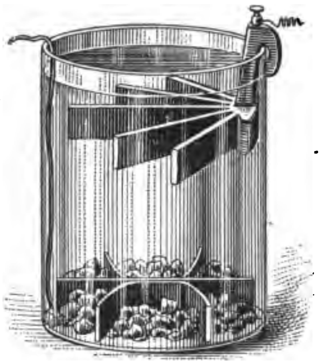


Fig. 327. — Crowfoot Gravity Cell

As the sulphuric acid acts upon the zinc, zinc sulphate is formed; this is less dense than copper sulphate, and they keep separate in the gravity cell without the porous cup.

Since polarization does not take place in the gravity cell, it maintains a practically constant difference of potential at its terminals, and is capable of giving a nearly constant current. This is the cell ordinarily used for telegraphic work.

When this cell is in good condition, the blue solution of copper sulphate should fill the jar to a little above the middle, and the line of separation between it and the zinc sulphate solution should be clearly defined. If the cell is unused for some time, the copper sulphate solution will reach the zinc, and copper will be deposited upon it. The cell can be brought back to its proper condition by *short-circuiting* it, that is, connecting the two terminals by a short piece of wire, for a few hours.

As the water evaporates, the zinc sulphate crystallizes in the form of white crystals around the edge of the jar, and unless this is coated with paraffin, the crystals will form over the top and down the outside of the jar.

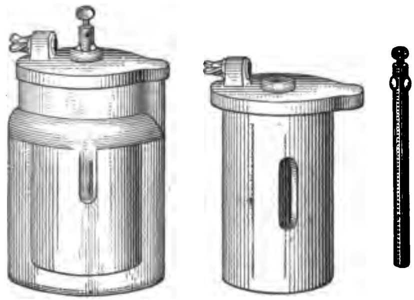


Fig. 328

385. The Leclanché Cell has in the center a porous cup containing a bar of carbon, around which is packed a mixture of manganese dioxide and coke. The top of the porous cup is sealed to keep the contents in place. The carbon is the positive pole and a rod of zinc at the side of the jar is the negative. The liquid used is a solution of ammonium chloride (sal ammoniac). This cell polarizes rapidly and is suitable for open circuit work only. It is largely used for electric bells. It needs but little attention after it is once properly charged. A modification of this cell is shown in Fig. 328.

Fig. 329. — Bichromate Cell

386. The Bichromate Cell. — In the bichromate cell and the chromic acid cell the chemical action upon the zinc goes on vigorously whether the circuit is open or closed, and for this reason the zinc is so arranged that it can be raised out of the liquid when the

current is not needed. A common form is that known as the bottle form, shown in Fig. 329. Two plates of carbon are suspended from the top of the bottle, while between them is a rod carrying at its lower end a zinc plate that can be raised and lowered at will.

The solution used may be either potassium bichromate or chromic acid, but the latter is the more convenient to make.

Chromic Acid Solution. — Dissolve 160 g. of chromic acid in 1420 c.c. of water, and add slowly, stirring all the while, 90 c.c. of sulphuric acid.

387. The Dry Cell is hermetically sealed at the top so that its contents cannot escape. The containing cup, *Zn* in Fig. 330, is of zinc, and one terminal of the cell is attached to it. The other terminal is at the top of a cylinder or plate *C*, composed of carbon and manganese dioxide. The space between this and the zinc cup is filled with a paste composed of one part by weight of zinc oxide, one part zinc chloride, one part ammonium chloride, three parts plaster of Paris, and two parts water. This is an open-circuit cell. It polarizes rather quickly, but is rapidly restored to its initial condition on breaking the circuit. This form of cell is sometimes used to furnish the spark for exploding the gas in automobile engines.

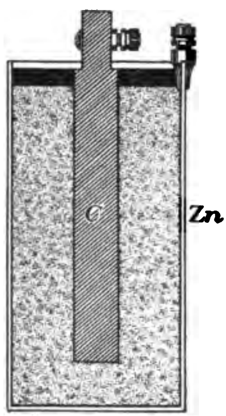


FIG. 330. — Dry Cell

388. Electro-motive Force, Current, Resistance. — The difference of potential at the terminals of a cell *when it is on open circuit* is its *electro-motive force*, or E. M. F. When the cell is sending a current, the difference of potential at its

terminals is less, — by an amount called the *loss of potential in the cell.* In Fig. 331 the cell with terminals A and D is sending a current through the circuit from A to B, C, D, and back to A. The sum of the differences of potential between A and B, B and C, and C and D, is equal to the difference of potential between A and D; and if to this we add the loss of potential in the cell, the sum is equal to the E. M. F. of the cell. The *practical unit* of E. M. F. and also of potential difference, is the *volt.*

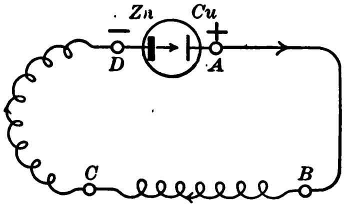


FIG. 331

When the two poles of a cell are connected by a conductor, as in Fig. 331, a current is said to flow from the + to the −. The *practical unit* of current is the *ampere.*

If we connect the poles of the cell by a short, heavy wire, and measure the current that passes, and if we then connect the poles with a long, thin wire, and again measure the current, we find that the greater current is passing in the first case. We see, therefore, that the wire has a certain property that affects the amount of current passing through it. This property is called *resistance,* the unit of which is the *ohm.*

The current of electricity passing along a wire is somewhat analogous to the flow of water in a pipe. The current or amount of water that flows through a pipe depends upon two things: (1) the difference between the water levels at the ends of the pipe, or the "head" of water; and (2) the size and smoothness of the inside of the pipe. The "head" or *difference of water pressure at* the two ends of the water pipe may be compared to the *difference of potential,* or difference of electrical pressure, at the ends of a wire; the *resist-*

ance to the flow of water in the pipe, depending on size and roughness, may be compared to the *resistance* to the electrical current, depending on the cross section and material of a wire; and the resulting *current* of water may be compared to the electrical *current.*

389. The Unit of Current, the Ampere. — The chemical, the magnetic, or the heating effect may be taken as a basis for measurement of currents. The chemical effect, however, is taken to define the unit, and the magnetic effect for practical use.

The *ampere* is that current that will deposit 0.001118 g. (0.01725 grain) of silver per second from a solution of silver nitrate. The same current will deposit 0.00032959 g. (0.005086 grain) of copper per second from a solution of copper sulphate (§ 421).

For the measurement of small currents the *milliampere*, or thousandth part of an ampere, is used as a unit.

390. The Unit of Resistance. — The *ohm* is defined as the resistance of a column of mercury the mass of which is 14.4521 g. and which has a uniform cross section, and a length of 106.3 ± cm. at 0° C. This is practically a column 106.3 cm. long and 1 sq. mm. in cross section. Ten feet of No. 30 copper wire has a resistance of 1.033 ohms.

A *megohm* is a million ohms. A *microhm* is one millionth of an ohm.

391. The Laws of Resistance. — The resistance of a conductor depends upon four things: *length, cross section, material,* and *temperature.* Experiment has determined the following laws:

I. *The resistance of a conductor is directly proportional to its length.*

II. *The resistance of a conductor is inversely proportional to its area of cross section.* For a wire a more convenient form of the law is that the resistance is inversely proportional to the square of the diameter of the wire.

III. *The resistance of a conductor depends upon its material.*

IV. *The resistance of a metallic conductor increases as its temperature rises. The resistance of carbon and electrolytes, on the other hand, decreases.*

The first three laws, for a wire, may be expressed by the formula

$$R = K\frac{l}{d^2}, \tag{53}$$

in which l is the length in feet, d the diameter in thousandths of an inch, or *mils*, and K is the resistance of 1 mil foot of the wire; *i.e.*, of a wire 1 foot long and 1 mil in diameter.

VALUES OF K AT 75° F.

Silver	9.76	Platinum	58.80
Copper	10.38	Iron	63.08
Aluminum	19.00	German silver	135.92

COPPER WIRE TABLE

Temperature = 75°F. Sp. gr. = 8.89

No.	Diam. in Mils	Ohms per 1000 Feet	Feet per Pound	No.	Diam. in Mils	Ohms per 1000 Feet	Feet per Pound
1	289.3	0.124	3.95	16	50.82	4.02	128.14
2	257.6	0.156	4.99	17	45.26	5.07	161.59
3	229.4	0.197	6.29	18	40.30	6.39	203.76
4	204.3	0.249	7.93	19	35.39	8.29	264.26
5	181.9	0.314	10.00	20	31.96	10.16	324.00
6	162.0	0.395	12.61	21	28.46	12.82	408.56
7	144.3	0.499	15.90	22	25.35	16.15	515.15
8	128.5	0.629	20.05	23	22.57	20.38	649.66
9	114.4	0.793	25.28	24	20.10	25.70	819.21
10	101.9	1.00	31.38	25	17.90	32.40	1032.96
11	90.74	1.26	40.20	26	15.94	40.47	1302.61
12	80.81	1.59	50.69	27	14.20	51.52	1642.55
13	71.96	2.00	63.91	28	12.64	64.97	2071.22
14	64.08	2.59	80.59	29	11.26	81.92	2611.82
15	57.07	3.12	101.63	30	10.03	103.30	3293.97

It is well to notice certain facts concerning the above table as follows: The diameter of wire for a certain number is one half as great as it is for the sixth number before it. The resistance and the number of feet per pound doubles every third number. If one remembers, for example, that copper wire No. 10 is practically 100 mils in diameter, has a resistance of 1 ohm per thousand feet, and contains 31.4 feet per pound, he can make a very good estimate for wire of any length and size.

392. Unit of Electromotive Force, the Volt. — The *volt* is the difference of potential required at the ends of a conductor, the resistance of which is 1 ohm, to send through it a current of 1 ampere.

The E. M. F. of a cell depends only upon the materials of which it is composed, and not at all upon its size or shape. The gravity cell gives nearly 1.1 volts; the Leclanché cell, about 1.5 volts; and the chromic acid cell, about 2 volts. Many attempts have been made to produce a *standard cell.* In such a cell it is not at all essential that the E. M. F. should be 1, but the E. M. F., whatever it is, should remain constant. The legal standard cell in the United States is the Clark cell. Its E. M. F. is 1.434 volts at 15° C. The Weston or cadmium standard cell has an E. M. F. of 1.0186 volts between 5° C. and 26° C. The standard cell is not used for the production of a current but for comparing its voltage with that of other cells.

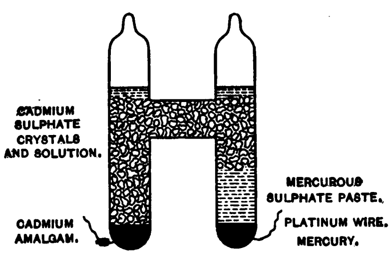


Fig. 332. — Weston Standard Cell

393. Ohm's Law, formulated as the result of experiment, is of very great importance. It is to the effect that the current varies directly as the electro-motive force and inversely as the resistance, and that their relation is expressed by the formula

$$I = \frac{E}{R}. \tag{54}$$

This may be written

$$\text{Amperes} = \frac{\text{Volts}}{\text{Ohms}}, \text{ or } A = \frac{V}{O}.$$

From this law we can find the current that a known E. M. F. will send through a certain resistance, the resistance through which a known E. M. F. will send a given current, or the E. M. F. required to send a certain current through a known resistance. The law may also be applied to difference of potential instead of to E. M. F.

394. Size and E. M. F. of a Cell. —**Demonstration.** — Couple the plates of a simple galvanic cell to a voltmeter, and note the reading. Diminish the distance between the plates and then lift one plate slowly until it is nearly out of the liquid. Observe that the reading of the voltmeter is not changed.

The size of a cell makes no difference in its E. M. F.

395. Internal Resistance of a Cell. —**Demonstration.** — Connect the cell used in § 394 to an ammeter, and observe that the current increases when the distance between the plates is decreased, and decreases while the plate is being lifted from the liquid.

Since the E. M. F. of the cell remains constant, this change in the current must be due to a change in the resistance of the cell. The resistance of a cell is called *internal resistance* and depends upon the size, shape, and material of the cell. It is this internal resistance that causes the loss of potential in the cell (§ 388).

396. Arrangement of Cells in a Battery; Series Grouping. — Whenever several cells are to be grouped in a battery, the question of how they shall be coupled together becomes an important one. As horses can be hitched to a wagon, either one behind the other (tandem) or side by side (abreast) so cells can be coupled either in series or in parallel. When two or more cells are coupled in *series*, the copper of one is joined to the zinc of the next, while the outside copper and zinc form the terminals of the battery, as A and B in Fig. 333. For this grouping the E. M. F. of one cell is added to that of the next, and the total internal resistance is the sum of the internal resistances of all the cells; hence Ohm's Law will be written

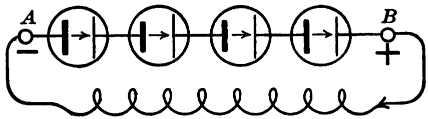


FIG. 333. — In Series

$$I = \frac{SE}{Sb + R}, \tag{55}$$

in which S is the number of cells in series; E, the E. M. F. of each cell; b, the internal resistance of each cell; and R, the resistances of all conductors and instruments through which the current passes.

EXAMPLE. — Suppose 4 cells to be coupled in series, the E. M. F. of each to be 1.02 volts, and the internal resistance of each 2.4 ohms, what current will they send through an external resistance of 27 ohms?

$$I = \frac{SE}{Sb + R} = \frac{4 \times 1.02}{4 \times 2.4 + 27} = \frac{4.08}{36.6} = 0.111 \text{ ampere.}$$

397. Parallel Grouping. — In the *parallel* or *multiple* method of grouping, the coppers are all joined to one terminal and the zincs to another. This gives the same result

as if all the plates were in one large cell. The E. M. F. is the same as it would be for a single cell, while the internal resistance is less. Ohm's Law will be:

$$I = \frac{E}{\frac{b}{P} + R}, \quad (56)$$

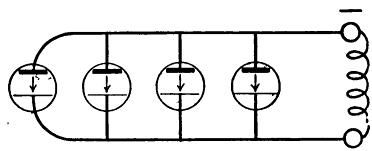


FIG. 334. — In Parallel

in which P is the number of cells in parallel.

EXAMPLE. — Suppose the same 4 cells as in § 396 to be grouped in parallel and to be coupled to the same resistance. What will be the current?

$$I = \frac{E}{\frac{b}{P} + R} = \frac{1.02}{\frac{2.4}{4} + 27} = \frac{1.02}{27.6} = 0.037 \text{ ampere.}$$

398. The Series and Parallel Grouping is a combination of the two methods given above. In Fig. 335 there are 6 cells arranged 3 in series and 2 in parallel. In Fig. 336 the same

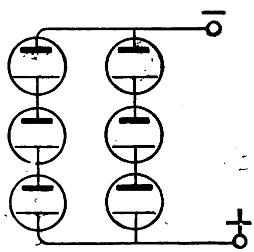


FIG. 335

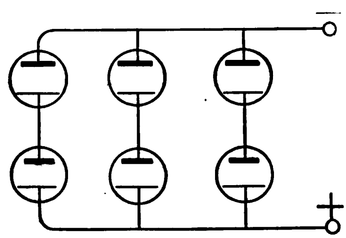


FIG. 336

6 cells are coupled 2 in series and 3 in parallel. In each case the total number of cells is the product of the number in series and the number in parallel. Ohm's Law applied to this coupling is:

$$I = \frac{SE}{\frac{Sb}{P} + R}, \quad (57)$$

in which each letter has the same meaning as in §§ 396, 397.

EXAMPLE. — If the cells in Fig. 336 are of the same kind as those used in § 396, with the same external resistance, then

$$I = \frac{SE}{\frac{Sb}{P} + R} = \frac{2 \times 1.02}{\frac{2 \times 2.4}{3} + 27} = \frac{2.04}{28.6} = 0.071 \text{ ampere.}$$

The formulas given for these different groupings are important, and are applicable to any form of continuous current generators, dynamos as well as cells.

399. Arrangement of Cells for Maximum Current. — In order to get the maximum current from a battery, the cells should be grouped in such a way that their internal resistance shall be as near as possible the same as the external resistance of the circuit. This means that if R is large, the cells should be grouped in series; if it is small, they should be in parallel; and if it is neither very large nor very small, such a grouping should be made as will make $\frac{Sb}{P} = R$, if possible.

400. Maximum Efficiency. — The arrangement for maximum current is not usually the one for maximum efficiency; for, if the internal resistance is equal to the external, just half the work of the current is spent in overcoming resistance in the cells; that is, the efficiency is just 50 per cent. The efficiency will increase if the external resistance is made large compared with the internal, for now the greater part of the work will be employed outside the cell. This means that a cell cannot work efficiently when sending a heavy current.

Questions

1. How does the current given by a cell differ from that given by the Holtz machine?

2. Why is it not necessary to use a porous jar in the gravity cell?

3. Will the current from a cell jump across a small air gap in the same way that the spark will jump from a Leyden jar?

4. Why will a light cotton covering insulate a current for an electric light, while it will not for the current from an induction machine?

5. Which will have the greater resistance, a spool wound full of small wire or a spool of the same size wound full of large wire? Give two reasons.

6. What is meant by a mil foot?

7. What effect will it have upon the internal resistance of a cell to move the positive and negative plates nearer together?

8. What effect will it have to increase the size of the plates?

9. Is it an economical use of a battery to couple the cells in such a manner as to get the maximum current?

10. What effect will it have upon the rate of work done by a battery if it is used at high efficiency?

Problems

1. What is the resistance of 2640 ft. of copper wire No. 18?

2. What is the resistance of iron wire having the same length and diameter?

3. What is the resistance of 100 ft. of German silver wire No. 30?

4. A Daniell cell, having an E. M. F. of 1.06 volts, and an internal resistance of 0.4 ohm, is coupled to a coil of wire having a resistance of 0.38 ohm. What current will pass through?

5. Four Daniell cells (E. M. F. = 1.06 volts, and an internal resistance of 0.4 ohm) are coupled in series and send a current through a resistance of 2 ohms. What is the value of the current in amperes?

6. What current will the same cells coupled in parallel send through the same resistance?

7. A gravity cell of 1.07 volts, with an internal resistance of 2.6 ohms, is coupled to an electric bell and push button. What will be the current if the resistance of the bell with the connecting wires is 5.8 ohms?

8. What will be the current if two cells like that in problem 7 are coupled in series on that circuit?

9. Find the current if the two cells are coupled in parallel.

10. Six cells each having an E.M.F. of 1.5 volts and an internal resistance of 1.2 ohms send a current through a resistance of 0.8 ohm. How must they be coupled to send the maximum current? How many amperes in this current?

11. How should the cells of problem 10 be coupled to send the maximum current through a resistance of 8 ohms? How many amperes in this current?

12. Find the external resistance when 2 dry cells, each having an E.M.F. of 1.5 volts and an internal resistance of 0.6 ohm, are coupled in series and send a current of 2 amperes through it.

III. THE EFFECTS OF THE CURRENT

401. Heating Effects. — **Demonstrations.** — Connect two dry cells in series with a short piece of German silver wire No. 30; the wire will become red-hot unless you have too long a piece. Use the same length of No. 30 copper wire and repeat. Can you explain the reason for any difference in result? Repeat, using a heavy current.

402. The Laws of Electric Heating. — The heat developed by a current in a circuit is proportional (*a*) to the square of the current, (*b*) to the resistance of the circuit,[1] (*c*) to the time during which the current passes. Hence,

$$H = mI^2Rt,$$

in which I represents the current in amperes, R the resistance in ohms, t the time in seconds, and m a constant factor

[1] The resistance of German silver is higher than that of copper.

depending on the kind of heat units in which it is desired to express H. If H is to be calories,

$$H = 0.24\ I^2Rt. \qquad (58)$$

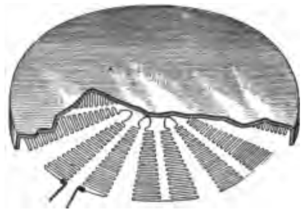


Fig. 337. — Base of Electric Heater, partly cut away

This heating effect is a waste in many uses of the current, such as in the conducting wires of a street railway, or of a system of electric lighting. It is called the *heat loss* and reduces the efficiency of the system. It is made use of, however, in *electric heating*, such as the heating of cars, in which the current passes through coils of resistance wire, and in cooking utensils, water heaters, toasters, flatirons, soldering irons, etc.

403. Fuse Wires. — Another useful purpose to which the heating effect is put is in fuse wires, which are made of some high-resistance alloy having a low melting point. If a short piece of such a wire is put into an electric circuit, it will melt if the current increases beyond its carrying capacity, and break the circuit.

Fig. 338. — Fuse Link

In this way a circuit designed to carry a certain current may be protected from an accidental overload. Fuses vary in form from the simple fuse wire to the wire with prepared ends (Fig. 338) called a fuse link, and the cartridge form of inclosed fuses that can be slipped into the terminals of the fuse block (Fig. 339).

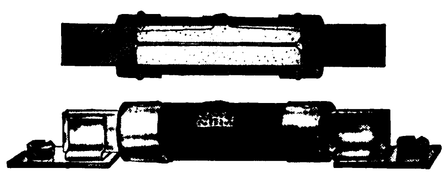


Fig. 339. — Cartridge Fuse

404. Magnetic Effects.—**Demonstration.**—Through the middle of a thick card with a smooth surface, like bristol board, thrust a piece of No. 12 copper wire. Connect the ends of this wire with a battery arranged to give its maximum current, and while the card is supported in a horizontal position, sift iron filings over it, and strike it lightly with a pencil. If the current is great enough, the filings will show that the wire is surrounded by circular lines of magnetic force having the axis of the wire for their center. A small magnetic needle will set itself tangent to these circles at any point. If the current passes up the wire, as in Fig. 340, the direction of the lines of force is counterclockwise. By the direction of the magnetic lines is meant, as in § 324, the direction in which the + end of the magnetic needle will point. If the current is sent down the wire, then the direction of the lines of force will be clockwise.

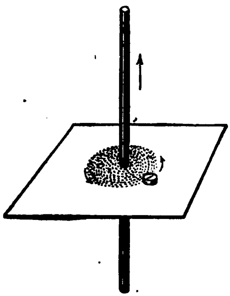


FIG. 340

While there is no difficulty in showing the magnetic effect of the current in a single wire by the use of a small magnetic needle or compass, it is necessary to use a current of from 20 to 30 amperes in order to show the circular character of the lines of force by the filings. If a current of this amount cannot be obtained, the same effect can be produced by sending a current of one ampere through a vertical coil (of about 25 turns) which pierces the card. Fig. 341 indicates how this may be done.

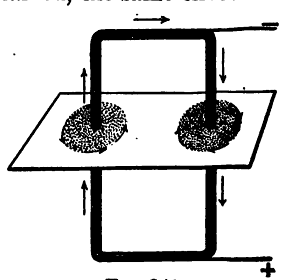


FIG. 341

The relation between the direction of the current flowing in a conductor and the direction of the resulting lines of magnetic force around it, may be stated as follows: *Grasp the conductor in the right hand, with the thumb pointing in the direction in which the current is flowing; then the fingers will point in the direction of the lines of magnetic force.*

405. Deflection of the Needle. — **Demonstration.** — Couple a battery to a straight wire AB (Fig. 342), and hold it above and parallel to a magnetic needle. The needle will turn from its position in the direction indicated in the figure. Place the wire *below* the needle, and the direction of its deflection is reversed. Change the direction of the current in the wire, and the needle is deflected as at first.

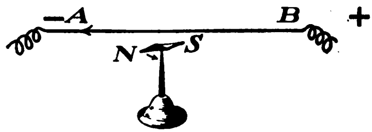


FIG. 342

This demonstration is important; it shows the principle of one class of measuring instruments. The relation between the direction of the current in the wire and the deflection of the *north* end of the needle is what we should expect from the direction of the lines of force around a current: *Place the right hand with the palm on the wire and turned toward the needle, and with the fingers extended in the direction in which the current is flowing; then the extended thumb will point in the direction of the deflection of the north end of the needle.*

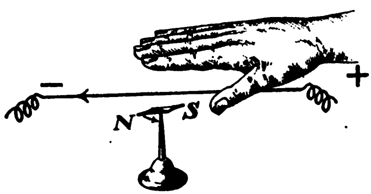


FIG. 343

406. Magnetic Properties of the Solenoid. — A *solenoid* is formed of a coil of insulated wire wound in the form of a cylinder in one or more layers.

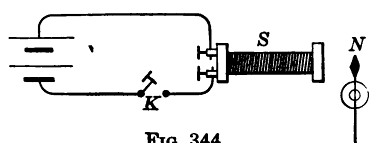


FIG. 344

Demonstration. — Place upon a table a magnetic needle, and let it come to rest. Place a solenoid S with one end about two inches from the north pole of the needle. Close the key K, sending the current through the solenoid, and the needle will be acted on at once, being

either attracted or repelled according to the direction of the current in the coil.

The length of a solenoid is usually great compared with its diameter, but its magnetic properties are still retained even if it is shortened to a single turn. Figure 345 shows lines of force of such a turn.

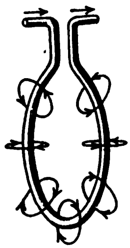


FIG. 345

An important use is made of the solenoid, in the circuit breaker which is used to protect electrical circuits from too heavy currents. Figure 346 gives, in diagram, the path of the current. When the current in the solenoid becomes too great, the iron plunger *P* is drawn up, strikes the brass pin *p*, which trips the catch *C*, that holds the arm *A* in place. The spring *S*, which is compressed when the breaker is closed by the handle *H*, pushes *A* out and breaks the contact between *A* and *B*. The amount of current required to pull up the plunger *P* depends upon its position, which is regulated by the thumbscrew *T*.

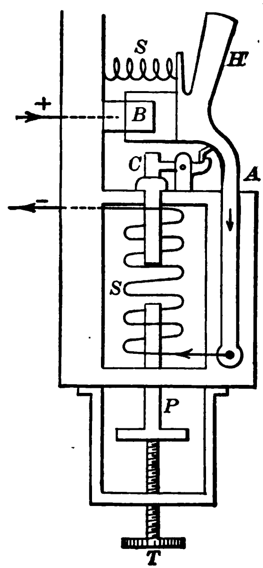


FIG. 346. — Solenoid Circuit Breaker

407. The Electromagnet. — If the solenoid is provided with a soft iron core, it becomes an *electromagnet*. Since the iron offers a better path for the lines of magnetic force than air, that is, a path having less resistance, the introduction of the iron increases the number of lines of force (maxwells) that a certain current will

generate on passing through the coil. This means that the magnetic strength of the electromagnet is increased.

FIG. 347

Demonstrations. — Make an electromagnet by winding several layers of insulated copper wire No. 16 around a wooden spool about a foot long, and putting a piece of gas pipe or soft iron rod inside the spool for a core. Couple with several cells of a battery, and when the current is turned on, dip the end of the core into a box of nails; lift the magnet and note the effect as shown in Fig. 347. Break the current. What is the result?

Support the same magnet vertically, and lay over the upper end a sheet of glass (Fig. 348) upon the under side of which a sheet of paper has been pasted. Sift over the plate an even layer of iron filings, and, tapping the plate lightly, turn on the current. The lines of force will be shown in a striking manner.

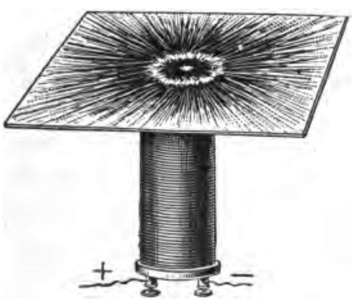


FIG. 348

408. Poles of an Electromagnet. — When the ends of a solenoid or an electromagnet are tested with a magnetic needle, it is found that the lines of force pass through the core in the direction we should expect from §§ 404, 405. Therefore, for determining the *poles* of an electromagnet, the following rule holds: *If the coil is grasped in the right hand with the fingers pointing in the direction of the current, then the thumb will point toward the north pole of the magnet.*

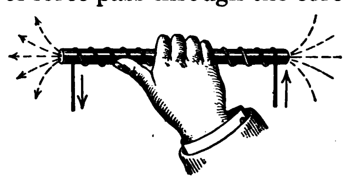


FIG. 349

409. The Horseshoe Electromagnet. — Since the object to be attained in an electromagnet is a strong magnetic field, the horseshoe form is the best. As commonly made, it consists of two spools wound with insulated wire and mounted on two cylindrical cores, which are fixed perpendicularly into a yoke of soft iron (Fig. 350). The wire is wound on the spool in such a way that if the cores and yoke were bent out into a straight line, *the winding would be all in one direction.* The piece of soft iron often provided for the magnet to attract (at the ends of the cores opposite the yoke) is called the *armature.*

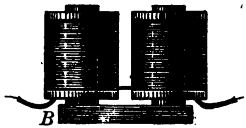


FIG. 350

The core of an electromagnet should be of such a quality of iron that it will lose its magnetism, or become demagnetized, as soon as the current is stopped. If there is a small amount of residual magnetism in it after the current is cut off, so that it will not release the armature promptly, paper can be pasted over the ends of the magnet to help overcome this defect. Annealing the cores will sometimes remove the difficulty.

The number of lines of force passing through the cores of an electromagnet depends upon two things; the number of turns of wire and the current through each turn. The product, called the ampere turns, is a measure of the strength of the magnet.

410. The Lifting Magnet. — In order that an electromagnet may have great lifting power, the air gap between the iron core and the iron to be lifted should be as small as possible, the path of the lines of force should be short, and the iron should offer little resistance to the lines of force.

Figure 351 is a cross section of an efficient form, and Fig. 352 shows the magnet in actual use, in transferring steel billets to or from a railroad car. The magnet is placed upon the iron or steel to be lifted, the current is sent through the coil, the magnet and its load are moved by a crane to the desired spot,

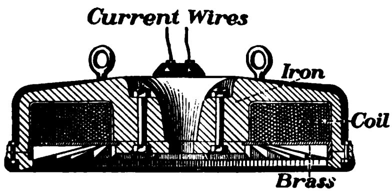


Fig. 351

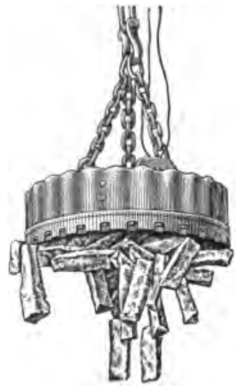


Fig. 352

and the load is dropped by breaking the circuit. If non-magnetic substances are to be lifted, they must be attached to an armature.

411. The Electric Bell.—The common electric bell is an application of the electromagnet. When the button B is pressed, it closes the circuit, and the current enters by the + binding post; passes around the electromagnet, then to the post P (Fig. 353), through which runs a pin that makes contact with the armature of the magnet by means of a light spring, then along the spring S to the – binding post. In bells having an iron base the base itself is made a part of the circuit. As soon as

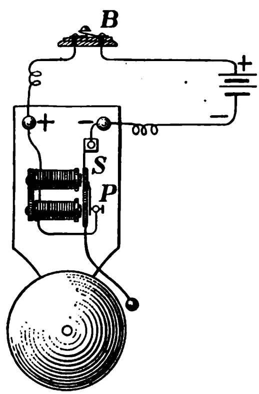


Fig. 353. — Electric Bell

the current passes, the armature of the electromagnet is attracted and the current is broken at P. When this happens the magnet no longer attracts the armature, and the spring S carries it back against the post P, again making the circuit. This causes the bell to ring automatically as long as the button is pushed. When two or more bells are to be rung from a single push button, they should be coupled in parallel, as they will not ring well in series unless they strike at exactly the same rate (Fig. 354).

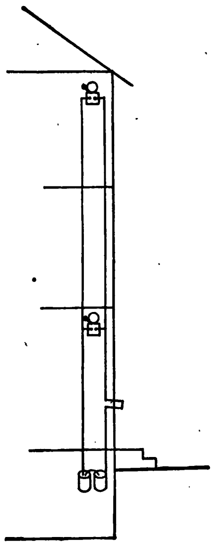


Fig. 354. — Diagram of Bells in Parallel

412. The Electric Telegraph. — It is evident that the electric bell can be used for signaling at a long distance. The telegraph, which is used especially for this purpose, depends upon the same principle: that of the electromagnet. The principal parts of the telegraph are the main battery and line, the relay, the local battery and circuit, the sounder, and the key.

413. The Key is simply a circuit breaker put in the main line, and so arranged that the current is sent every time the lever K (Fig. 355) is pressed down. When the key is not in use for sending messages, the switch S is closed, making contact so that messages can be received.

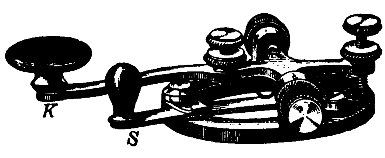


Fig. 355. — Telegraph Key

414. The Main Battery consists either of a group of gravity cells or of a dynamo. There is usually a main battery at each end of the line.

415. The Line consists of iron or copper wire supported by glass insulators attached to the line poles. At one terminal station the + pole of the main battery is connected with the line and the − pole is connected with the earth or is "grounded," while at the other terminal station the − pole is connected with the line and the + is grounded.

416. The Relay is an electromagnet of high resistance in series with the main line. Its function is to make and break contact in the local circuit which controls the sounder. It has nothing whatever to do with strengthening the current in the sounder, which gets its current from the local battery only. When a current from the main line passes through the relay, its armature is attracted, current from the local battery passes through the sounder circuit, the sounder armature is attracted and makes a loud click from which the message is read. The way in which this is done will be seen by referring to Fig. 357. The relay is wound with a great many turns of fine wire, so that the small main current may be able to magnetize it.

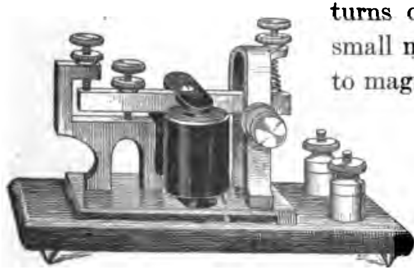


FIG. 356. — Sounder

417. The Sounder is an electromagnet, in the local circuit, from which the message is read. This sounder is wound with fewer turns of wire of a larger size than that used in the relay, because the current is comparatively large in the local circuit.

418. Connection and Operation of the Line. — Let Fig. 357 represent, diagrammatically, a line having Philadelphia and New York for its terminal stations and Trenton for an intermediate station. The connections are arranged for sending a message from New York to Philadelphia. The switch S at Philadelphia is closed, that at New York is open. When

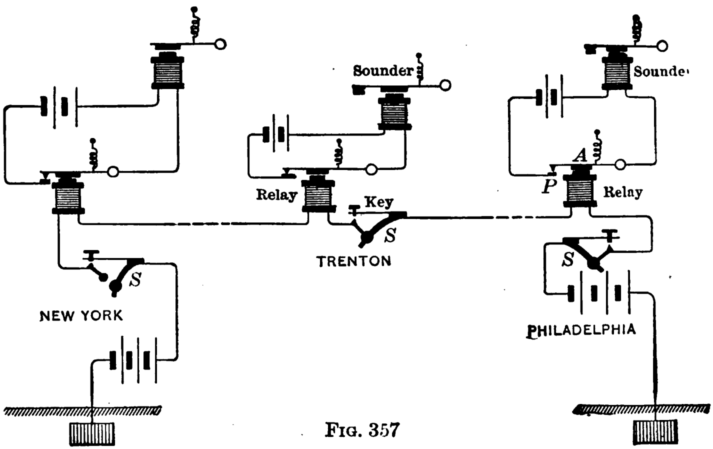


FIG. 357

the operator at New York presses his key, the connection is made along the line, and the relay at Philadelphia is magnetized. The armature A is attracted, moves toward the magnet, and comes in contact with the pin P; and as this is coupled to one side of the local battery and the armature to the other side through the sounder, the local circuit is made and the sounder attracts its armature. As soon as the sender at New York releases his key, the circuit is broken, A is pulled back to its normal position by a spring, the local circuit is broken, and the condition is just as it was before the signal was sent.

The message sent to Philadelphia may also be read at

Trenton; for the current has the same effect on any intermediate relays that it has on the Philadelphia relay. If the message had been intended for Trenton, the New York operator would have first sent the Trenton "call" until the Trenton operator had responded, showing that he would pay attention.

419. The Telegraphic Alphabet. — Telegraphic messages are sent by what is known as the Morse alphabet. This consists of a series of dots and dashes with intervals between the letters and longer intervals between the words.

In the first instruments there was used a special receiver that traced the dots and dashes upon a strip of paper. The universal custom now is to read by sound.

The Morse Alphabet

A -—	H ----	O - -	U --—
B —---	I --	P -----	V ---—
C -- -	J —-—-	Q --—-	W -——
D —--	K —-—	R - --	X -—--
E -	L ——	S ---	Y -- --
F -—-	M — —	T —	Z --- -
G ——-	N —-		

420. Chemical Effects. — **Demonstrations.** — Fit corks to the two sides of a U-tube. Through these corks pass copper wires with platinum terminals. Fill the tube nearly to the top of the terminals with a solution of sodium sulphate (Na_2SO_4) colored with blue litmus. Couple two or three cells in series to the copper wires, and in a few minutes the solution in the U-tube near the + terminal will turn red, showing the presence of an acid, while the color at the − terminal shows the presence of an alkali.

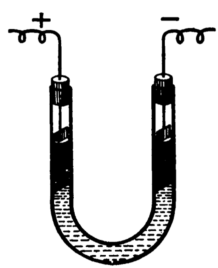


Fig. 358

Rinse the U-tube used in the above experi-

ment, and fill it nearly full of water to which a few drops of sulphuric acid have been added. Cut a notch along the side of each cork and couple three dry cells in series. Bubbles of gas will be noticed at each terminal. Those given off at the + terminal are oxygen and those at the − terminal are hydrogen.

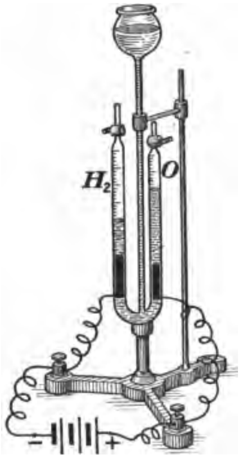


FIG. 359

The relative quantities of the gases given off at the terminals can be measured by using a form of apparatus like that shown in Fig. 359. This is known as Hoffman's apparatus, and with it the hydrogen collected over the negative terminal is shown to be twice the volume of the oxygen collected over the positive terminal.

The action of the current shown in these demonstrations is called *electrolysis*, and the solution in which this action goes on is an *electrolyte*. The apparatus used in electrolysis is called a *voltameter;* and the terminals, *electrodes*. The electrode by which the current enters the electrolyte is called the *anode*, and that by which it leaves, the *cathode*. The parts into which the current separates the electrolyte are called *ions;* that which goes to the *cathode* is called the *cation;* and that which goes to the *anode* is called the *anion*. From the direction which the ions take in the electrolyte their electric condition is determined; hence the cation is considered electropositive and the anion electronegative.

In the experiment with sodium sulphate the Na_2SO_4, on going into solution, breaks up into positively charged ions, $+Na$, and negatively charged ions, $-SO_4$. When the SO_4 ions, sulphions, reach the positive platinum plate, as they will by mutual attraction, they give up their negative charge

and attack the water, forming H_2SO_4, and setting O free. The Na ions give up their positive charge to the negative plate, attack the water, and form NaOH, setting H free.

421. Electrolysis of Copper Sulphate. — **Demonstration.** — Send a current through a solution of copper sulphate placed in the U-tube, Fig. 358, and it will be found that bubbles of oxygen rise from the anode, while the cathode will be coated with copper.

The action of the current in this demonstration is to separate the $CuSO_4$ into $+Cu$, which goes with the current toward the cathode and is deposited upon it, and $-SO_4$ which goes toward the anode and decomposes the H_2O of the solution H_2SO_4, setting oxygen free.

422. Electrometallurgy. — If a copper anode is used in the last demonstration, the SO_4 will unite with it, forming $CuSO_4$, keeping up the strength of the solution and eating away the copper. If a plate of impure copper is used as the anode, the copper deposited on the cathode will be pure, the impurities being left in the solution.

When lead ores are reduced to metallic lead in a furnace, there is usually with the lead a small quantity of silver. In order to obtain pure lead to be used in paints, the pig lead containing the silver is used as the anode, and a lead plate as cathode. When the current is sent through the bath, pure lead is transferred from the anode to the cathode, while the silver is left in the bath as a residue. The silver is afterwards recovered from the solution, and forms an important by-product.

423. Electroplating is the process of coating one metal with another by means of the electric current. The article to be coated is the cathode of the cell and is coupled to the anode of a battery. Copper may be deposited from a bath

of copper sulphate, silver from one of the double cyanide of silver and potassium, nickel from one of nickel ammonium sulphate. Nickel plating is used to protect from oxidation articles made of brass, iron, or steel.

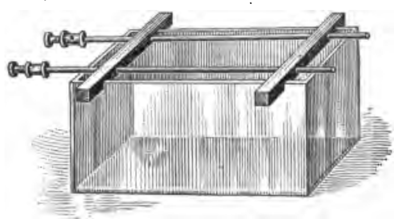


FIG. 360. — Tank for Electroplating

In commercial electroplating the electrolyte is in a large tank along each side of which runs a heavy copper rod. The articles to be plated are suspended from one rod, and a plate of the metal to be deposited, from the other. A dynamo that gives a heavy current and low voltage is used, the current being sent through the tank from the metal plate to the articles to be plated. These articles must be chemically clean on the surface. The necessary potential difference at the two rods varies with the metals deposited.

424. Electrotyping. — The process of electrotyping is used to make copies of type, medals, or other objects. The object to be copied is thoroughly cleaned and a mold is taken from it in wax or plaster of Paris. A careful dusting of the surface with some conducting substance, as graphite, is necessary; then the mold is suspended in the proper solution by a wire from the anode of a battery, the current is turned on, and the deposit begins. When the coating is thick enough so that it can be taken from the mold without bending, it is removed and backed by melted lead or type metal.

425. Storage Cells. — If a galvanometer is coupled to the terminals of a voltameter after a current has been sent

through it, the needle will be deflected, showing that the voltameter is itself capable of giving out a current.

Demonstrations. — Fasten two sheets of lead to the opposite sides of a wooden support and suspend them in a jar of dilute sulphuric acid. Connect the cathode of two or three dry cells coupled in series, to one of the plates and the anode to one terminal of a double snap switch. Couple an electric bell to the plate and switch as shown in Fig. 361. Send the current from the battery through the cell for a short time — a second or two will answer — then snap the switch, the battery will be cut out, the bell will be thrown in circuit with the cell and will begin to ring. The action will be strong at first and gradually die out.

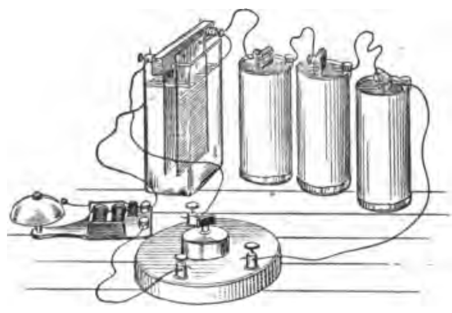


FIG. 361

Repeat and note the effect of the length of time the battery is sending a current upon the length of time the bell will ring.

Repeat, using a 2-volt, 1-candle power incandescent lamp instead of the bell.

It will be observed that there is a vigorous production of oxygen from the anode and of hydrogen from the cathode of the lead-sulphuric acid cell. The oxygen combines with the lead of the anode forming lead peroxide (PbO_2) which covers the plate a chocolate brown. When the bell is put in the circuit, the current passes through the cell in the opposite direction and the lead peroxide on the anode is changed to a spongy form of lead. Planté was the first to discover this effect and devised this form of battery for the storing of

electrical energy. In recent forms of this battery the lead plates, or *grids*, are grooved in such a way that the grooves can be filled with a paste of red oxide of lead for the positive electrode and litharge for the negative.

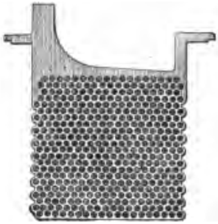


FIG. 362

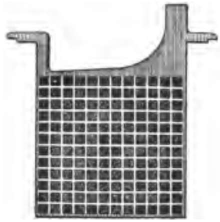


FIG. 363

FIG. 364

There are many types of storage cells in practical use. Figure 362 shows the positive and Fig. 363 the negative electrode of the chloride accumulator cell, and Fig. 364 shows one of the smaller cells ready for use. The large size of the plates reduces the internal resistance of the cell and makes a heavy current possible.

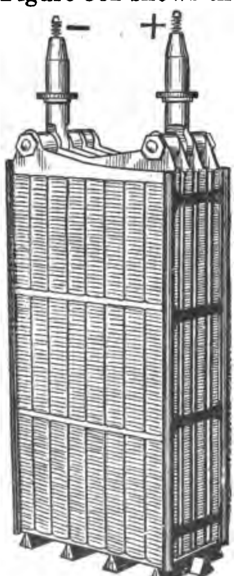


FIG. 365. — Edison Storage Cell

FIG. 366. — Steel Containing Can

Storage batteries are used as the motive power in electric automobiles and trucks. An efficient type is the Edison cell (Fig. 365), in which the liquid used is a solution of caustic potash and the electrodes are nickel hydrate and iron oxide, the nickel being the positive

electrode and the iron the negative. The containing cans (Fig. 366) are made of corrugated sheet steel which secures the cells against breakage.

Questions

1. Which will affect the heating of a wire more, to double its resistance or to double the current passing through it?

2. Why does a fuse wire melt on an electric circuit when the copper wire carrying the current does not?

3. Describe a way of determining the direction of the current in a wire that is concealed under a molding.

4. Suppose Fig. 367 to represent the end of a horseshoe magnet with the current passing in the coils in the direction indicated by the arrows. Apply the rule for finding the polarity of an electromagnet and mark the poles. Write a new rule which will show the relation between the polarity and the clockwise or counter-clockwise passing of the current around the core.

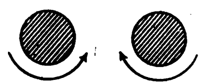


FIG. 367

5. Suppose a current is passing in a clockwise direction around a coil of two or three turns of wire hanging in a vertical plane. What will be the direction of the magnetic axis of the coil?

6. Name four uses of the lifting electromagnet.

7. What kind of iron should be used for the core of an electromagnet? Why?

8. What is the source of current for the relay of a telegraph line?

9. What is the source of current for the sounder?

10. How could a silver cup be given a gold lining by the electric current?

11. What is stored in the storage cell, electricity or electric energy?

Problems

1. How many calories will be developed in a resistance of 15 ohms by a current of 9 amperes flowing for 20 min.?

2. A 110-volt lamp requires a current of 0.5 ampere and its hot resistance is 220 ohms. Five of these lamps are used in a room for 2.5 hr. How much heat is developed?

3. How many calories of heat will be generated by an electric toaster the resistance of which is 20 ohms when carrying a current of 5.5 amperes for 5 minutes? What voltage will be required?

4. 100 ft. of copper wire No. 30 is joined in series with 100 ft. of iron wire No. 30. How many calories are developed in each wire per hour when a current of 2 amperes is sent through it?

5. To what temperature will 1 liter of water at 8° C. be heated in 5 minutes in an electric water heater which takes 11 amperes on a 110-volt circuit? (Make no correction for loss in the heater.)

IV. ELECTRICAL MEASUREMENTS

426. Electrical Quantities. — The three quantities most necessary to measure in electricity are *current, resistance,* and *electromotive force.*

427. Instruments Used in Measurements; Galvanometers. — A *galvanometer* is an instrument that shows the intensity of a current passing through it, by the amount of the deflection of a needle (§ 405) or other moving part. It is calibrated by determining experimentally the relation between the current and the corresponding deflection, and indicating this on a graduated scale. A galvanometer of small resistance, if calibrated to read in amperes, is called an *ammeter.* If the resistance of a galvanometer is known, the potential difference that sends the current can be readily determined. A galvanometer of high resistance, calibrated to read directly in volts, is called a *voltmeter.*

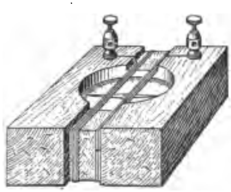


FIG. 368

The *detector galvanometer* (Fig. 368), or *galvanoscope,* is used rather to show the presence of a current than to measure its intensity. A simple form can be made by using a

small compass for the needle, setting this in a block, and winding a few turns of insulated wire around it. By connecting the ends of the coil to binding posts, the instrument is completed and will answer for many experiments.

428. The Solenoid Galvanometer. — One principle used in the construction of galvanometers is that which determines the following phenomenon: If an iron rod is suspended with one end inside a coil of wire, the rod will be pulled into the coil as soon as a current is sent through the wire — the strength of the pull depending on the strength of the current used.

FIG. 369

One advantage that the instrument has is that its controlling force is the action of gravity upon the weight on the balance arm. This insures that after its calibration has once been made it will remain constant. Figure 369 represents a commercial ammeter made on this principle. It will be observed that the divisions on the scale are not equal. This is due to the fact that when the core is drawn into the coil, it is moving into a stronger magnetic field.

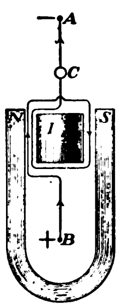


FIG. 370

429. The d'Arsonval Galvanometer. — Another principle used in the construction of galvanometers — a most important one — is employed in the instrument shown in Fig. 370. Between the poles of a horseshoe magnet placed vertically there is fixed an iron cylinder *I*. A coil of fine wire wound on a thin copper frame is suspended from the point *A*, so that it will swing freely between the cylinder and the magnet poles. When a current is sent

through it, the coil becomes a magnet with its poles in a line perpendicular to the line joining the poles of the horseshoe magnet, and at once, because of the influence of the horseshoe magnet, it is deflected. The controlling force is the torsion of the wire supporting the coil. The readings are taken either from a pointer and a scale, or from the reflection of a fixed scale from a mirror fastened to the coil at the point *C*. This instrument has the advantage of being dead beat; that is, it will come to rest quickly without vibrations.

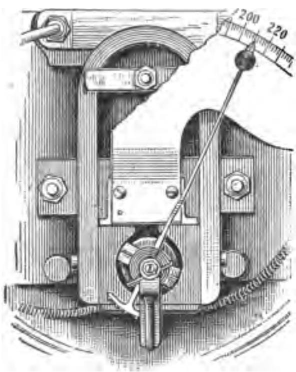


FIG. 371

Figure 371 shows how the d'Arsonval principle is applied in a commercial voltmeter. The wire suspension is replaced by a spiral spring which serves to carry the current and control the position of the pointer. The coil is at right angles to the pointer and its axis is held between jeweled pivots. The magnetic field is strengthened by soft iron pole pieces bolted to the magnet and nearly surrounding the coil.

430. The Measurement of Potential Difference. — A voltmeter is a high resistance galvanometer and hence takes so little current that it does not materially change the *difference of potential* of the points it connects. It is for this reason that a voltmeter will indicate nearly the E. M. F. of a cell (§ 394). In measuring the difference of potential between the points in a circuit, the voltmeter is connected with them in parallel.

431. The Measurement of Current. — A current of electricity is generally measured by an ammeter, or low resistance galvanometer, put in series in the circuit. Its resistance is so low that its introduction into a circuit usually makes no material change in the *current* of that circuit.

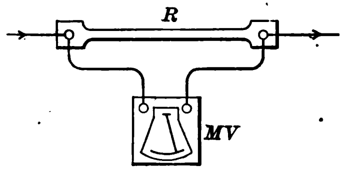


FIG. 372

Another method of measuring current is to measure the potential difference at the ends of a known resistance when the current is passing through it (Fig. 372). Many commercial ammeters are made on this plan. The resistance must be accurately known and a delicate millivoltmeter used. If R equals 0.001 ohm and each scale division of the millivoltmeter indicates a fall of potential of 0.001 volt, then the current in the line is 1 ampere per scale division. If R equals 0.01 ohm and the millivoltmeter is calibrated as before, the current is 0.1 ampere per scale division.

432. The Resistance Box. — Resistances may be measured by comparing them with known resistances. These known resistances are usually made of coils of resistance wire contained in a box like that shown in Fig. 373. For all coils except those that are of very small resistance, a wire is used that has a high specific resistance, *i.e.*, one in which the value of K (§ 391) is high, — such as German silver. For all coils, however, it

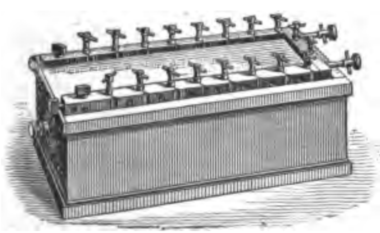


FIG. 373. — **Resistance Box**

is best to use a wire that has a low temperature coefficient (§ 391). An alloy called platinoid, which has a temperature coefficient less than half that of German silver, is frequently used. When the terminals of a battery are connected with the binding posts of the box, the amount of resistance introduced into the circuit is determined by the number of plugs that are taken out. If all the plugs are in the box, the resistance is practically zero. If the plug T (Fig. 374) corresponding to the 1-ohm coil is pulled out, the current, in going from the piece A to the piece B, must go through that coil, so that the resistance is 1 ohm. The resistances are generally 0.1, 0.1, 0.2, 0.3, and 0.4 ohm; 1, 2, 3, and 4 ohms; 10, 20, 30, and 40 ohms; and 100, 200, 300, and 400 ohms. This makes it possible to introduce any number of ohms from 0.1 ohm to 1111.1 ohms. The coils are wound double, as shown in Fig. 374, to keep the coil from being a magnet as soon as a current passes through it (§ 406), and also to prevent self-induction, a phenomenon that will be discussed later.

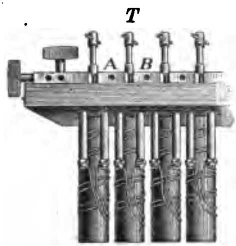


FIG. 374

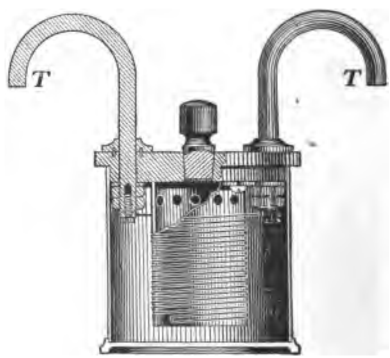


FIG. 375

If the resistance coils are to be used as standards, great care is taken to prevent accidental changes in their resistance. Such a coil shown in Fig. 375 is wound on a cylinder which is inclosed in a metal tube. This

tube is pierced with holes and is immersed in oil to keep the temperature of the coil constant. A thermometer can be inserted through the hole in the top on removing the plug. The terminals *T* of the coil are very heavy, are carefully insulated, and contact is made by the use of mercury cups.

The *rheostat* is a kind of resistance box used for regulating dynamo and motor currents. The common ironclad rheostat consists of resistance wire wound in such a way that it can be put into or taken out of a circuit by moving a metallic arm over a set of contact points. Fig. 376 shows the face surface of a cast-iron enameled rheostat, Fig. 377 shows the under side. The resistance wire is entirely embedded in the enamel, while the contact points project through it. The position of the arm determines the amount of resistance in the circuit.

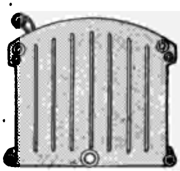


FIG. 376

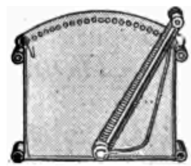


FIG. 377

433. The Fall of Potential along a Conductor. — Demonstration. — Stretch a high-resistance wire 1 m. long on a board between two binding posts *A* and *B* (Fig. 378). Climax wire No. 18, or

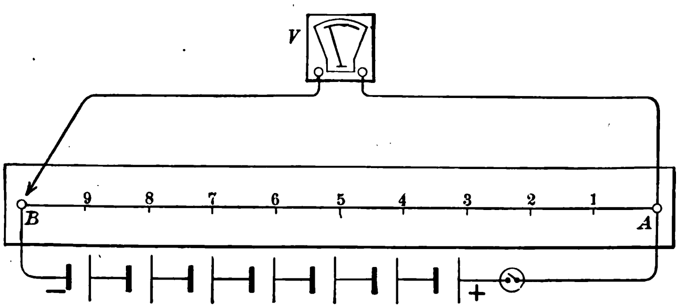


FIG. 378

German silver No. 24, will answer. Couple a half dozen or more cells to the binding posts with a snap switch in the circuit. Couple

one terminal of a low-reading voltmeter to A and the other terminal to a wire that can be touched to the wire AB at any point. On sending the current through AB and touching the voltmeter wire to B the voltmeter reading will show the fall of potential for the whole length of AB. Touch the wire at the points 9, 8, 7, and the reading of the voltmeter will be nine tenths, eight tenths, and seven tenths, respectively, of the reading for AB. In order to prevent the polarization of the cells the current should be left on only just long enough to get each reading.

It will be found that *the fall of potential is directly proportional to the length of the wire.*

434. The Measurement of Resistance. — (*a*) *The Fall of Potential Method* is well adapted to the requirements of practical electricians, because the only instruments needed are an ammeter and a voltmeter.

Demonstration. — Couple an ammeter A (Fig. 379) in series with the resistance R to be measured. To the terminals B and C of this resistance couple a voltmeter V, as shown. Make the current by the switch S, and read both instruments *at the same time.* Substitute these readings in

$$R = \frac{E}{I} = \frac{V}{A},$$

derived from Ohm's Law, and the value of R is determined.

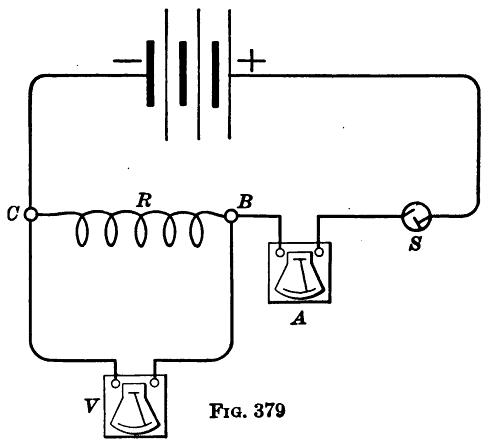


Fig. 379

It is to be observed that the reading of the ammeter gives the sum of the currents through the resistance R and through

the voltmeter. On account of the high resistance of the voltmeter, the current will usually be so small that it may be neglected.

(*b*) *The Method of the Wheatstone Bridge.* — The voltmeter circuit from the point B to the point C in Fig. 379 is called a *shunt circuit,* or a *parallel circuit.*

Wheatstone made use of the fall of potential in parallel circuits for the measurement of resistance. When two points A and B (Fig. 380) are connected by two parallel circuits, the total fall of potential in the upper branch AxB is equal to the total fall in the lower branch AyB. There must be a point y in the lower branch where the fall of potential from A is exactly the same as the fall of potential in the upper branch from A to x; so that the points x and y will have the same potential. If, then, the points x and y are connected by a wire, no current will flow in the wire. If, however, a wire is connected from x to a point z between A and y, a current will flow from z to x. If the connection is made to a point w, between y and B, the flow will be from x to w. By the introduction of a galvanometer in the conductor xy, the proper position of y in which no current

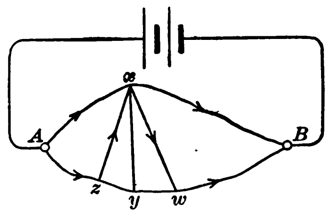


FIG. 380

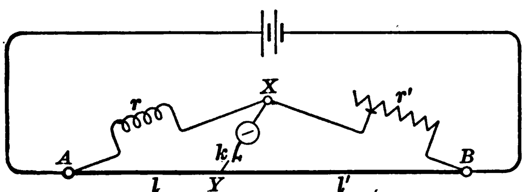


FIG. 381

passes in xy can readily be determined, and when this is found, the resistance of Ax : the resistance of xB = the resistance of Ay : the resistance of yB.

In the *slide wire Wheatstone bridge* (Fig. 381) the circuit AYB is a single wire of uniform diameter; hence its resistance is proportional to its length, and the proportion becomes $r : r' = l : l'$, in which r and r' are resistances and l and l' lengths. The key k is used to make contact with the wire in determining the position of Y. For XB is put the resistance box, while AX is the resistance to be measured.

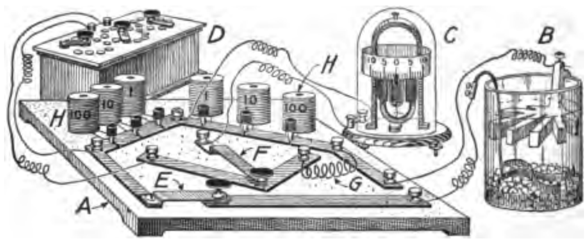


FIG. 382.—*A*, Wheatstone Bridge; *B*, Battery; *C*, Galvanometer; *D*, Resistance Box; *E*, Battery Key; *F*, Galvanometer Key; *G*, Material to be tested; *HH*, Spools of proportional resistance

Figure 382 shows a form of Wheatstone bridge in which the slide wire is replaced by spools of resistance wire HH. These can be put into the circuit by taking out the short-circuiting plugs and any, or all of them, can be used.

435. The Combined Resistance of Circuits in Series.— The resistance of 100 feet of a given wire is twice the resistance of fifty feet of the same wire. This is evident when we consider the expression for the resistance of a wire $R = K\frac{l}{d^2}$. Since the resistance is directly proportional to the length, the final resistance is the same whether the wire is all in one

piece or in two pieces joined together end to end. When conductors are coupled in series (Fig. 383), each adds its own resistance, so that the combined resistance of circuits in series is $R = r + r' + r''$ etc., in which r, r', and r'' are the individual resistances of the circuits that are joined in series.

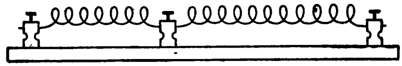


FIG. 383

436. The Combined Resistance of Parallel Circuits is always less than that of either circuit alone. The reason for this is evident when we consider the expression for the resistance of a wire, $R = K\frac{l}{d^2}$. The putting of two wires in parallel, in place of one of them, is equivalent to increasing the diameter of that one.

Demonstration. — Wind a coil of iron wire No. 18 and couple its ends to two binding posts A and B, Fig. 384. Measure its resistance. Wind a second coil of No. 18 copper wire, couple it to A and B and measure its resistance. Couple both coils to A and B and measure the combined resistance. The last resistance will be less than either of the others.

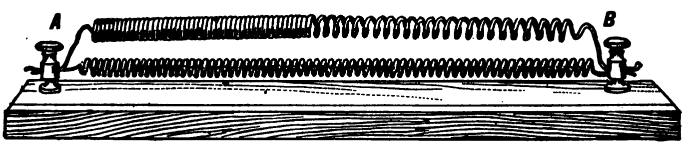


FIG. 384

A careful study of the results of the above demonstration will help the student to understand the conditions which govern the resistance of parallel circuits.

To find an expression for the combined resistance of a cir-

cuit and its shunt, we can take the case of a galvanometer with its shunt (Fig. 385). The current passing through the galvanometer may be written $G = \frac{V}{g}$, in which G is the current, g the resistance of the galvanometer and V the potential difference at its terminals. The current through the shunt may be written $S = \frac{V}{s}$. The entire current will be $I = \frac{V}{R}$, in which R is the combined resistance of the galvanometer and its shunt.

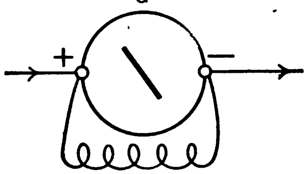


FIG. 385

Since $$I = G + S,$$

$$\frac{V}{R} = \frac{V}{g} + \frac{V}{s}, \text{and } \frac{1}{R} = \frac{1}{g} + \frac{1}{s}; \text{ whence, } R = \frac{gs}{g+s}. \qquad (59)$$

In general, the parallel resistance of two circuits is the product of the two resistances divided by their sum. The parallel resistance of several circuits is found by finding the value of R in the expression $\frac{1}{R} = \frac{1}{r} + \frac{1}{r'} + \frac{1}{r''} + \frac{1}{r'''}$, etc. In the case of any number of equal resistances, incandescent lamps for example, the parallel resistance of n lamps is $\frac{1}{n}$th the resistance of a single lamp.

The arrangement shown in Fig. 385 is frequently used when we wish to measure a current greater than the galvanometer will carry safely. A shunt that will carry $\frac{9}{10}$ of the current, so that the galvanometer will read $\frac{1}{10}$ of the true value of the current, is called a *tenth shunt.*

437. The Resistance of a Cell may be found by measuring its E. M. F. with a high-resistance voltmeter (§ 430), and

then measuring the current it will send through an ammeter, the resistance of which is known. Ohm's Law may be written in the form $I = \frac{E}{R + r}$, in which R is the external resistance and r the internal resistance · from this,

$$r = \frac{E}{I} - R.$$

For example, if the voltmeter reads 1.1 volts, the ammeter 0.4 ampere, and the resistance of the ammeter is 0.1 ohm, we have

$$r = \frac{1.1}{0.4} - 0.1 = 2.65 \text{ ohms}.$$

In practice the resistance of the ammeter is often assumed to be zero, and the internal resistance is taken as $r = \frac{E}{I}$.

438. The Energy of Electric Currents. — The energy required to send a current varies directly as the current and also as the potential difference. When a difference of potential at the terminals of a circuit is 1 volt and this sends a current of 1 ampere through the circuit, the power developed is 1 watt, or $\frac{1}{746}$ horse power (§ 78). In any circuit the number of watts equals the number of volts × the number of amperes; *i.e.*, $W = VA$. The number of watts required to burn a certain tungsten lamp in which a current of 0.363 ampere is used, on a 110-volt circuit, will be $110 \times 0.363 = 40$ watts. The practical unit of power is the kilowatt, equal to 1000 watts. The kilowatt equals $\frac{4}{3}$ horse power and one horse power equals $\frac{3}{4}$ kilowatt. The practical unit of work is the kilowatt hour, or the work done in one hour at the rate of 1 kilowatt — namely 3,600,000 joules.

The work done in burning incandescent lamps is measured

in watt hours; the charging of a storage battery, in kilowatt hours. A battery of 55 cells, charged from a circuit giving a potential drop of 110 volts across the battery terminals and sending a current of 25 amperes through the cells for one hour, would have 2.75 kilowatt hours of work done on it.

Questions

1. Suppose you should couple a detector galvanometer to a circuit of unknown polarity. How would you determine the polarity?

2. Why is the iron core of a solenoid galvanometer drawn into the coil?

3. Does the direction in which the current passes through the movable coil of a d'Arsonval galvanometer make any difference with the direction in which it turns?

4. What would be the effect of leaving out the shunt of the millivoltmeter when using it to measure current?

5. Why must the ammeter and voltmeter, used in the fall of potential method of measuring resistance, be read at the same time?

6. Why do two wires coupled in series have a greater resistance than either wire?

7. Why do two wires coupled in parallel have a smaller resistance than either?

8. What method should you use in measuring the resistance of a galvanometer? Why?

Problems

1. A wire 2 m. long has a potential difference at its ends of 6.3 volts. What is the potential difference between one end of the wire and points 0.6 m., 0.9 m., 1.5 m., and 1.8 m. distant? Make a curve to show the results.

2. A certain lamp requires 6.6 amperes and 80.5 volts to run it properly. What is the resistance of the lamp?

3. Suppose the lamp in problem 2 is coupled to a 110-volt circuit. What resistance must be put in series with it?

4. The difference of potential at the ends of a branched circuit of 9 and 13 ohms is 11 volts. What is the current through the 9-ohm

branch? Through the 13-ohm branch? What is the total current? What is the combined resistance of the two branches?

5. A resistance board (Fig. 386) has in it five 110-volt, 16-candle-power lamps and one 55-volt lamp. The 110-volt lamps require a current of 0.5 ampere each. What is the resistance per lamp? The 55-volt lamp requires a current of 1 ampere. What is its resistance? What is the resistance, in parallel, of 2 of the 110-volt lamps? Of 3? Of 4? Of 5? Of one 110-volt lamp and the 55-volt lamp in parallel?

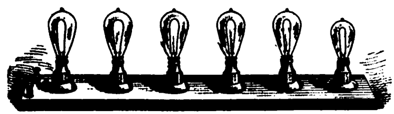


FIG. 386

6. An electric toaster requires 6 amperes on a 110-volt circuit. How many watts of electric power will it use? What will it cost to run it 10 minutes each morning for 30 mornings if electric energy costs 9 cents per kilowatt-hour?

7. What is the resistance of a tenth shunt for a galvanometer, the resistance of which is 13 ohms?

8. A storage battery is to be charged from a 110-volt circuit. The charging current must not exceed 5 amperes. If the internal resistance of the battery is 2.5 ohms, what external resistance must be placed in series with the battery? How many 110-volt 16-candle-power lamps in parallel would give the required resistance?

9. The slide wire in a Wheatstone bridge is 1 m. long. A balance is obtained when 452 mm. of the slide wire corresponds to 2 ohms in the resistance box and the rest of the wire corresponds to a coil of unknown resistance. Find the resistance of the coil.

V. INDUCED CURRENTS AND THE DYNAMO

439. Parallel Currents. — **Demonstration.** — Wind a spiral 3 cm. in diameter, of about thirty turns of No. 24 insulated copper wire. Suspend it from a rod and couple the upper end to the + pole of a battery. Straighten out a short piece of the lower end of the coil and let it dip into a drop of mercury which is connected with the − pole of the battery. When the current is turned on, the spiral will shorten and lift the end from the mercury. A spark will pass, then the spiral will lengthen, the point will again touch the mercury, and the action will be repeated.

FIG. 387

This demonstration shows, in a simple way, one result of the mutual action of parallel currents. Experiment has proved the truth of the following law:

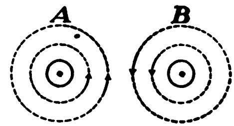


FIG. 388

I. *Parallel currents flowing in the same direction attract each other, and those flowing in opposite directions repel each other.*

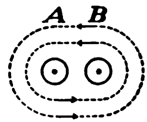


FIG. 389

It will be observed that this law is directly opposite in *form* to the statement of the fundamental law that lines of magnetic force going in the same direction *repel* each other (§ 327). That the two laws are statements of the same phenomena, however, can be shown by a consideration of Figs. 388, 389, 390.

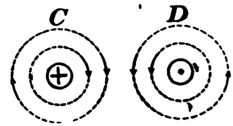


FIG. 390

In the case of *A* and *B*, which are carrying currents in the same direction (toward the observer), the lines of force between the wires are going in opposite directions. This means that the lines of force will run into each other and, by shortening,

FIG. 391

tend to bring the wires together, with the lines of force inclosing both, as in Fig. 389.

In conductors C and D, in which the currents are moving in opposite directions, the lines of force between the wires are in the same direction, and repulsion is the result. Among the many ways of showing this tendency of the lines of force to contract and move the conductor is the following:

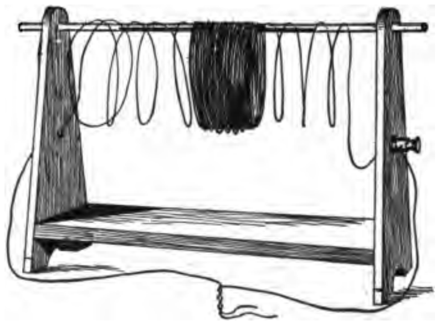


FIG. 392

Demonstration. — Suspend a coil of loosely wound insulated copper wire over a horizontal glass tube as shown in Fig. 391. On sending a current through the coil the wires will move together, Fig. 392. An iron rod placed in the tube will bring the wires together more quickly.

440. Induced Currents. — (a) *When the Conductor is Moved.* — **Demonstration.** — Make a coil of insulated copper wire No. 30, that will slide easily over a long bar magnet, and couple it to a sensitive galvanometer. Place the coil around the magnet at the middle and when the needle of the galvanometer is quiet, suddenly slip the coil off the + end of the magnet. The galvanometer will give a sudden throw, and then gradually come to rest at zero. Place the coil again at the middle of the magnet, and slip it off over the − end. Again there will be a throw of the needle, but in the opposite direction. Taking the

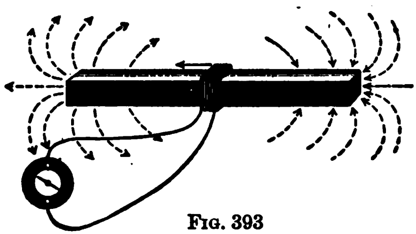


FIG. 393

magnet in one hand and the coil in the other, slip the coil *on* the magnet from the − end. Note the direction of the deflection. Again, slip the coil *on* the magnet from the + end, and notice the direction of the deflection.

The currents produced in this demonstration are *induced currents*, and they are produced by *the cutting of magnetic lines of force by an electrical conductor*. The demonstration shows that the currents produced depend for their direction upon the direction in which the conductor cuts the lines of force. By varying the speed of slipping off the coil, we shall find that the amount of current depends upon the number of lines cut in a given time. The relation between the direction of motion of the conductor, the direction of the lines of force, and the direction of the induced current, is shown in Fig. 394. If a conductor AB is held horizontally and allowed to fall in a magnetic field, cutting the lines of force as shown, then there will be set up at the ends A and B a difference of potential which will tend to send the current from A to B. This important law may be stated as follows:

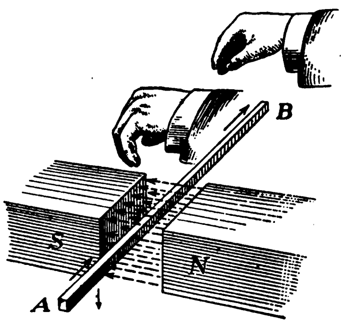


Fig. 394

If a person, holding a conductor horizontally, stands at a + pole looking in the direction of the lines of force, and lets the conductor fall, the induced current will flow toward the right hand.

Various other rules have been devised to express the law. One of these is as follows: Hold the thumb and the first and

second fingers of the right hand in such a way that each shall be perpendicular to the direction of the other two; turn the hand so that the thumb shall point in the direction of the motion, and the first finger in the direction of the lines of force; then the second finger will point in the direction in which the induced current flows.

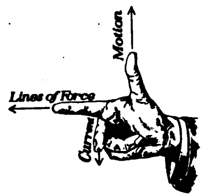


FIG. 395

The rate at which the lines of force are cut determines the induced E. M. F., 1 volt being induced in a conductor when it cuts 100,000,000 lines of force (maxwells) per second.

Since lines of force are closed circuits, it is sometimes convenient to consider a coil of wire and these lines of force as being *linked* with each other. In this case the induced E. M. F. is directly proportional to the *rate of change in the number of linkages.*

(*b*) *When the Magnet is Moved.* — **Demonstration.** — Couple a coil of small insulated wire, called a *secondary coil,* to a sensitive galvanometer. Thrust the + end of a long bar magnet into the coil as shown in Fig. 396, and observe the throw of the needle. Pull the + end out suddenly and compare the throw with that obtained at first. Repeat both experiments with the − end of the magnet.

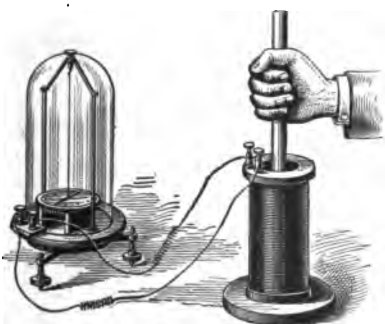


FIG. 396

This demonstration, compared with the preceding, shows that it makes no difference whether the coil or the magnet is moved. *A current is induced whenever magnetic lines of force are cut by a conductor.*

441. Primary and Secondary Coils.—**Demonstrations.**—Select a coil of large wire, called a *primary coil,* of such a size that it will easily go inside the secondary, and connect it with a battery. Thrust it into the secondary coil as you did the bar magnet in the last demonstration, and the same results will be obtained. Why?

Fig. 397

Place the primary coil inside the secondary and introduce a switch between the primary and the battery. Make the circuit and notice the deflection. Break the circuit and again notice the deflection. Compare the directions of these deflections with those obtained in the above demonstration by moving the primary.

Vary the demonstration by introducing a resistance box between the primary coil and its battery, instead of the switch. When a steady current is allowed to pass, there will be no deflection of the galvanometer. If the amount of current in the primary is changed, however, either increased or diminished, the throw of the needle will show the existence of an induced current.

Experiment has shown that the following laws hold true for induced currents:

I. *Whenever the current in the primary coil is either made or increased, there is induced in the secondary a current in the opposite direction.*

II. *Whenever the current in the primary coil is either broken or diminished, there is induced in the secondary a current in the same direction.*

442. Self-induction. — We have just seen that a change in the current in one coil induces a current in a second coil near the first. It is evident that a change of current in one turn of a coil should also induce currents in adjacent turns

of the same coil. This effect is called *self-induction,* and its existence can be shown as follows:

Demonstration. — Couple a battery, switch, galvanometer, and coil as shown in Fig. 398. Turn on the current, and observe the direction of the deflection. Bring the needle back to zero, and keep it there by placing a cork at one side to stop it. Break the current, and notice that there is a throw of the galvanometer in the opposite direction, showing that the current induced in the coil is in the same direction as the current sent by the battery.

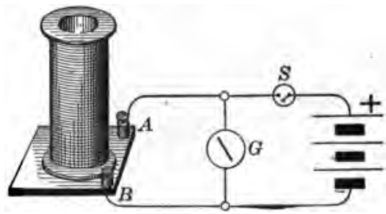


Fig. 398

Let Fig. 399 represent five turns of wire surrounding an iron core, carrying current away from the observer in 1, 2, 3, 4, 5, and toward the observer in 1′, 2′, 3′, 4′, 5′, as indicated. To understand the reason for self-induction let us assume that the current is just beginning, and is increasing in intensity. Let us consider the effect of the lines of force set up around turn No. 3 by the current passing through it.

As the current increases in strength the lines of force expand from wire No. 3 as a center, and pass through the iron core and around the outside of the wire. As they increase in diameter they cut across conductors 2 and 1 to the left, and across conductors 4 and 5 to the right. By applying the rule for the direction of induced currents (§ 440), we see that in all these conductors the induced current is in a direction *opposite* to the current already passing in the coil. When the current in the coil is broken, the lines of force contract to the conductor that produced them; they cut

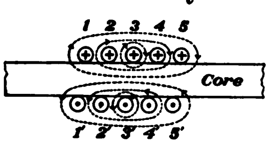


Fig. 399

the other turns in the opposite direction, so the induced current is reversed and in the *same* direction as the current in the coil. The same reasoning applies to every turn of the

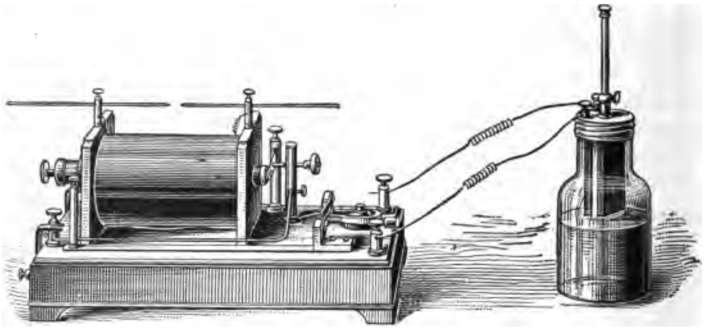


FIG. 400. — Ruhmkorff Coil connected with Cell

coil. This means that when the current is broken, the lines of force belonging to every turn of the coil cut every other turn in the coil, and the result is a self-induced current of considerable strength.

443. The Induction Coil, or *Ruhmkorff coil,* is a combination of coils used for the purpose of getting induced currents of high potential difference. Figure 401 is a diagram showing the relation of the parts in an induction coil. The essential parts are a soft iron core, a primary coil of large insulated wire connected with the battery, a secondary coil of a very much larger number of turns of fine insulated wire connected with binding posts A and B, an automatic make-and-break arrangement at P, between the primary coil and the battery, a condenser C connected with the primary circuit on each side of P, and a switch S.

The operation of the coil is as follows: When the switch is turned on, the current passes through the primary and

makes a magnet of the iron core. This attracts the soft iron armature, which is fastened to a light spring, and breaks the current at *P*. As soon as this is done, the core is no longer a magnet, the armature is thrown back by the spring, the contact is again made at *P*, and the action is repeated. When the current is made in the primary coil, a current in the opposite direction is induced in the secondary, and when the current in the primary is broken there is an induced current in the same direction in the secondary. The self-induction of the primary when the current is made acts against the battery current flowing in it, and reduces the induced E.M.F. in the secondary; but when the current is broken, the self-induction acts with the battery current and increases the E. M. F. of the secondary. The effect of the condenser is to increase the capacity of the primary coil and to shorten the time of breaking, thus raising the E. M. F. of the secondary. It also discharges through the battery, immediately after the current is broken, in a direction contrary to the battery current; this helps to demagnetize the core quickly. Since the current in the primary drops from a maximum to zero much faster than it rises from zero to maximum, the induced E. M. F. in the secondary is correspondingly higher at the break than at the make.

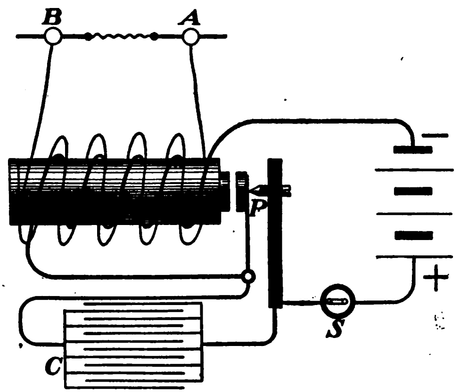


FIG. 401

Rev.

The induced current is of high voltage because the total number of cuttings of the lines of force (§ 440) is made very great — in two ways: the lines of force of the primary coil are increased in number by the presence of the iron core; and the secondary coil is made up of a very large number of turns of fine wire, thus increasing the number of times that each line of force is cut.

Since the E. M. F. rises so high in an induction coil the insulation should be as nearly perfect as possible. In modern coils the secondary is wound in sections, and these thoroughly coated with insulating wax under conditions that secure the removal of all air.

444. Effects of the Inductive Discharge. — The mechanical and heating effects of the inductive discharge are practically similar to those obtained from the discharge of the Holtz or Wimshurst machine, and the experiments made with the machine may be repeated and added to, using the induction coil instead. The physiological effects are peculiar. They should be obtained by taking hold of the terminals of the secondary, in a *small* coil. The effect from a large coil is often painful.

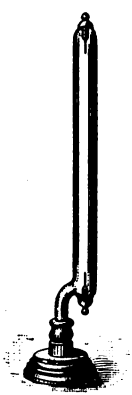


Fig. 402

445. Luminous Effects. — The difference of potential necessary to give a spark 1 cm. long across an air gap between two parallel plates is given by Lord Kelvin as 30,000 volts. If, however, the terminals are separated by air at a reduced pressure, the spark loses its intense brilliancy, and may be increased in length. This condition is secured by sealing platinum wires (§ 278) into the opposite ends of a glass tube (Fig. 402) from which nearly all the air has been removed. When this tube is attached to the secondary terminals of a Ruhmkorff coil, in a dark room, and the current is turned on, the tube will be filled with a band of violet light.

Geissler Tubes (Fig. 403) are glass tubes of various forms, supplied with platinum terminals and filled with different gases at different pressures. When placed in the current from the secondary of an induction coil, they give out many brilliant luminous effects. Commercial application of the light from a vacuum tube is made in the mercury arc lamp, in which the arc is carried by mercury vapor in a state of incandescence.

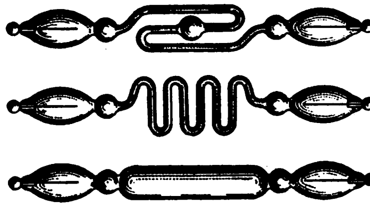


FIG. 403

The spark from an induction coil can be used to show the conductivity of glass. If a piece of small glass tubing is drawn down to an internal diameter of about 1 mm., and then slipped over the terminals

FIG. 404

of the coil (Fig. 404), a spark can be sent through the tube. This heats the tube, and after a time the spark goes from the terminals to the glass, which conducts the current. If this is continued, the heat finally melts the glass.

446. The Dynamo is a machine for the production of an electric current by the use of mechanical force. We have seen that whenever the lines of magnetic force are cut by a conductor, a galvanometer coupled to the ends of the conductor shows the presence of an electric current. In a dynamo there must be a magnetic field to furnish the lines of force, conductors in which the induction takes place, and a means of moving the conductors across the lines of force. This motion sets up an electromotive force at the ends of the conductors, and by coupling these ends to an external circuit a current is obtained.

447. The Ideal Simple Dynamo. — Under ideal conditions for a simple dynamo, the conductors would move in a uni-

form magnetic field. The nearest approach to this condition is obtained by using permanent magnets for the fields *N* and *S*, Fig. 405; a machine of this kind is called a *magneto*. By applying the laws for induced currents we may determine the direction of the current produced by the dynamo. Suppose the single coil in Fig. 405 is turned from its vertical position, clockwise. At the beginning of the movement, the motion of the conductor is almost parallel to the lines of force so that there will be little cutting of the lines, and little induction; but the rate at which the lines of force are cut increases until the coil reaches the horizontal position, and then decreases, until, when the conductor has passed through 180° and is again vertical, the induction again becomes zero. As the upper branch descends, the direction of the induced current with reference to a person looking from *N* to *S* will be from the left toward the right as in Fig. 394. The induction in the lower part of the loop, as it rises, will be from right to left, and thus the two currents will join and flow in the same direction. Every time the coil passes through the vertical position, the direction of the current induced in it changes, so that there will be two alternations of current for every revolution.

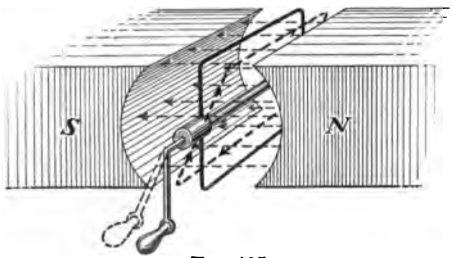


FIG. 405

448. The Commutator. — In order that the current taken from the coils of a dynamo may be in one direction, the ends of the coils are connected with copper terminals that revolve

with the shaft, and the currents are taken off by fixed brushes. A two-part commutator, suitable for a single coil, is shown in Fig. 406. A study of this figure will show that the brushes can be placed in such positions that the change from one commutator bar to the other shall take place just as the direction of the current in the coil changes; and for this reason the current in the external circuit will always be in one direction. The commutator usually consists of as many copper bars, or segments, as there are coils of commutator wire. Figure 407 shows the commutator ready to be fixed to the dynamo shaft. Each bar has a radial projection at one end with a slit in it, into which two wires are soldered. These wires are the end of one coil and the beginning of the next. The commutator bars are insulated from each other by mica strips and from the shaft by thin mica rings.

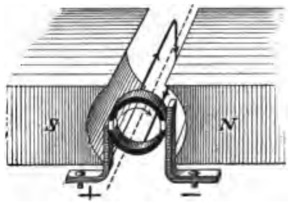


Fig. 406

Fig. 407.—Commutator

449. The Armature.—The part of the dynamo in which the electromotive force is induced is called the *armature*. This is generally a rotating part, but in certain types of machines it is stationary, in which case the magnetic field rotates. The *core* of the armature is made of soft iron in order to increase the number of lines of force by reducing the reluctance

in the magnetic circuit. *Reluctance* in a magnetic circuit corresponds to resistance in an electrical circuit, except that there is no substance through which the lines of force will not pass. In most armatures the conductors lie in slots cut into the surface of the core parallel to the axis.

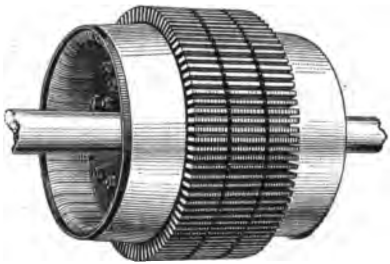


FIG. 408. — Core of Drum Armature

450. The Ring Armature consists of a number of coils of insulated wire wound upon a core which has the form of a ring. Figure 409 shows a simple form of ring armature. By applying the rule for direction of induction, we may determine the brush with which the + terminal is connected. Since one half of the whole number of coils is in series between the brushes on each side, it is evident that the E. M. F. will be the sum of the E. M. F.'s induced in all the coils on either side. The resistance of the armature will be one fourth of the resistance of all the wire upon it, since there are two parallel circuits from the + to the − brush, each having half the wire upon the armature (Formula 59). This form of armature is adapted to machines designed for high voltage, such as those used in arc lighting.

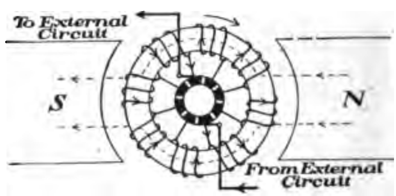


FIG. 409

451. The Drum Armature consists of conductors wound lengthwise upon a cylinder of iron. The ends of each coil

are connected to adjacent commutator bars. This form is used for lower E. M. F. than the ring armature. If a large current is to be taken from the machine, the conductors are made of copper bars or rods.

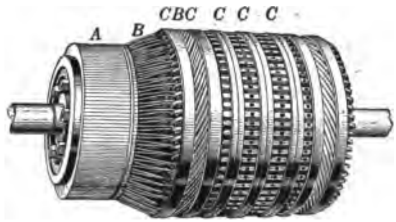


FIG. 410. — General Form of Drum Armature

A, commutator; *B*, wires; *C*, bands to hold wires in slots

452. The Field Magnet. — There are several methods employed to produce the magnetic field, and these determine the classes to which dynamos belong.

The frame of a dynamo may take any one of a number of forms. In Fig. 411, which shows the frame of a two-pole machine, the poles of the electromagnet are marked *N* and *S*. *C* and *C′* are the cores upon which the magnetizing coils are wound, and *Y* is the yoke, which is of iron or steel, and forms a path for the lines of force between the magnet cores. The core of the armature is marked *c*, and the air gap in which the lines of force are cut by the conductors is in the space between the core, *c*, and the face of either pole.

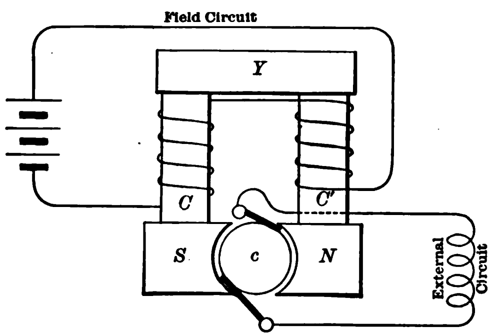


FIG. 411

Dynamos having more than one pair of poles are called *multipolar*. Those having two pairs are four-pole, those with three pairs are six-pole, and so on. The number of poles is regulated by the use to which the machine is put.

453. The Separately Excited Dynamo has a magnetic field produced by a current from some outside source of electricity, such as a battery (Fig. 411) or another dynamo. The advantage of this arrangement is that this outside current may be regulated so that it shall be constant, thus keeping the magnetic field constant.

454. The Series Dynamo has a field produced by a coil of large wire, wound on the field magnets, that is in series with the external circuit. Figure 412 shows how the connection is made from the upper brush around the field magnets, then through the external circuit, and back to the lower brush. If the resistance of the external circuit is increased, the current decreases, and consequently the magnetization of the field and the E. M. F. of the dynamo are decreased. If the resistance of the external circuit is decreased, both the magnetization of the field and the E. M. F. of the dynamo increase.

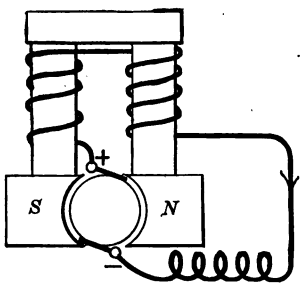


Fig. 412.—Series Dynamo

455. The Shunt Dynamo. — In the very useful form called the *shunt dynamo*, the wire wound on the field magnets is a long coil of small wire coupled to both brushes as a shunt to the external circuit. If the resistance of the external circuit increases, less current passes in that circuit, more

current passes through the shunt, and the magnetism of the field is increased, causing the E. M. F. of the machine to rise. If the resistance of the external circuit decreases, the E. M. F. of the dynamo falls.

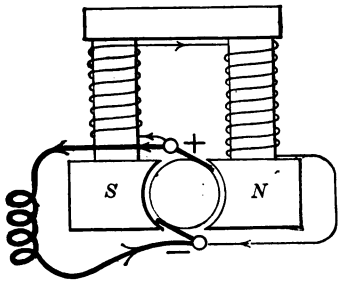


Fig. 413. — Shunt Dynamo

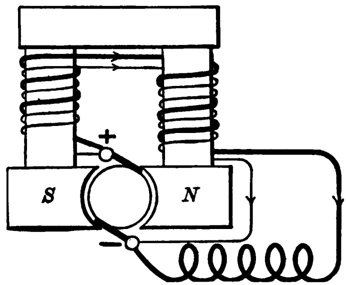


Fig. 414. — Compound Dynamo

456. The Compound Dynamo. — Since the E. M. F. of the series dynamo increases with the current in the external circuit, while the E. M. F. of the shunt dynamo diminishes as the current in the external circuit increases, it is possible to wind both a series and a shunt coil on the same field magnets, and so to proportion them as to keep the E. M. F. practically constant at all loads. The compound dynamo is wound in this way and is the machine used for incandescent lighting.

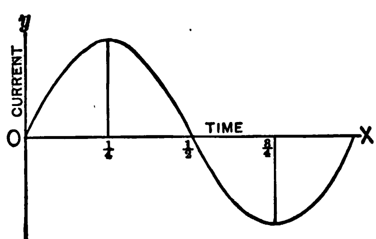


Fig. 415

457. The Alternating Current. — The electromotive force generated in the ideal simple dynamo of Fig. 405 goes through a definite cycle of change, and when the current passes into an external circuit it also goes through a similar cycle. If time

is laid off on the axis OX and current on the axis yy', the curved line of Fig. 415 will represent the changes that take place in an alternating current during the time of a single cycle.

In the first quarter of the time the current has increased from zero to a maximum in one direction. It then diminishes until at the end of one half the time the current is again zero. Reversal then takes place and the current rises to a maximum in the opposite direction in three fourths of the time and at the end of the cycle the current is again zero.

In the alternating current used for lighting there are 60 of these cycles per second.

458. The Alternator. — If the coils of a dynamo are coupled to copper rings instead of to the bars of a commutator, the current will be an alternating one, changing its direction twice for every rotation of each coil (Fig. 416). By using as many pole pieces to the field as there are coils, and by coupling the coils properly, the currents in all the coils are put in series, giving an alternating current of high E. M. F. The field magnets of an alternator are usually magnetized by a current from a small direct-current machine called an *exciter*. Figure 417

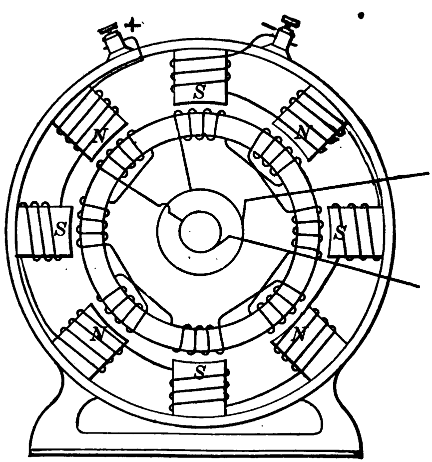


FIG. 416

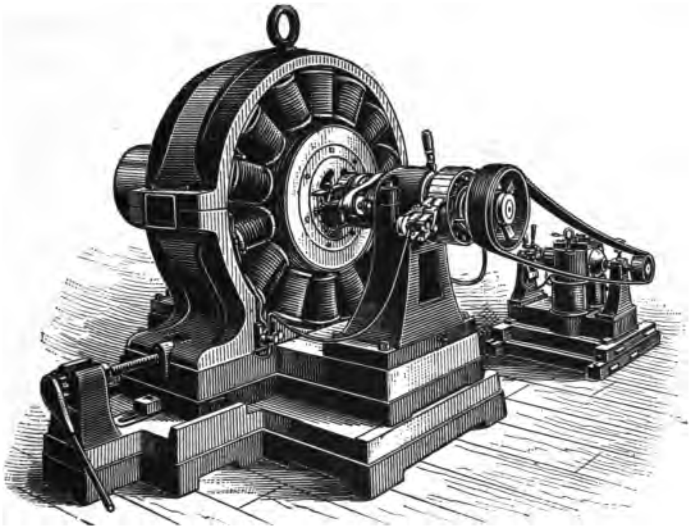


FIG. 417

shows the exciter at the right, belted to the pulley on the alternator shaft: its current is fed into the stationary field magnets supported by the frame. The armature coils are wound as flat coils on the surface of the rotating core.

FIG. 418

Figure 418 represents an alternator with revolving field magnets and a stationary armature. In this machine the exciter is direct con-

nected, that is, run on the alternator shaft. The collector rings, outside the commutator of the exciter, lead its current to the field of magnets. The armature wire is wound in slots on the inside of the stationary frame, and the cutting of the lines of force is produced by the sweeping of the rotating magnetic field across the stationary conductors.

459. Lenz's Law. — A person can turn the armature of a 50-H.-P. dynamo with one hand so long as there is no current generated and nothing to overcome but the friction; but when the dynamo is being run at full speed and the current is being used, the work of an engine is needed to turn it; the increase is the work that is required to force the conductors, while they are carrying a current, through the invisible lines of magnetic force. This is in accordance with Lenz's law, which can be stated thus: *Whenever a current is induced in a conductor by passing it through a field of force, the direction of the induced current is such that the lines of force generated by it around the conductor will oppose the motion that induces the current.*

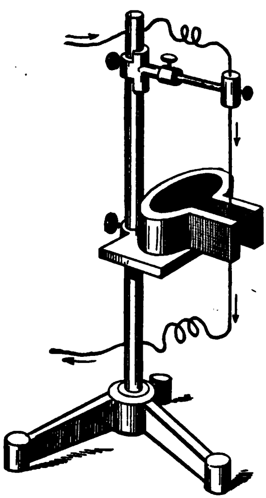


Fig. 419

460. The Electric Motor. — We have learned that when a wire is carried through a magnetic field, cutting the lines of force, a current is generated in the wire. The converse of this is also true: if a current is sent through a wire that is in a magnetic field, the wire will be set in motion in a direction contrary to that which would have

produced the current. In general any dynamo is reversible and can be used as a motor.

Demonstration. — Support a horseshoe magnet having a strong magnetic field in a horizontal position as shown in Fig. 419. Send a current through a No. 30 copper wire that is hanging vertically between the poles. As soon as the current is turned on, the wire will move out from between the poles, and if the current is strong enough, it will swing around to the outside of the N pole. The reason for the motion of the wire is seen if we apply the law of the mutual action of magnetic lines of force to the magnetic field around the wire when it is between the poles of the magnet. Let Fig. 420 represent a horizontal section through the wire and magnet. The direction of the lines of force will be indicated by the arrow points for both the permanent and temporary fields. On the left of the wire the lines of force are in the same direction and the repulsion between them pushes the movable wire to the right.

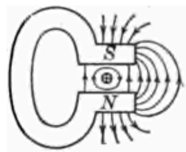


Fig. 420

If we apply the same law to the mutual action between the two sets of lines of force in the air gap of a motor, the cause of the rotation of the motor will be explained. Let Fig. 421

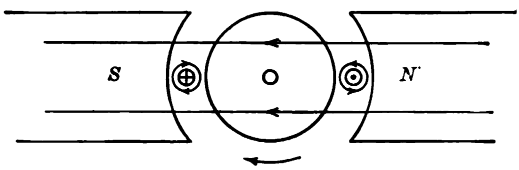


Fig. 421

represent a single turn of wire in the air gap. The direction of the lines of force generated around the conductor by a current that is approaching the observer, as on the right side of the figure, is counter-clockwise. The reaction between these lines of force and those generated by the field magnets will be repulsion above the wire, since the lines of

force there have the same direction, and attraction below it, since the lines of force there have opposite directions. The result is a tendency to drag the wire downward.

The direction of the lines of force around the wire on the left side of the figure, in which the current is going away from the observer, is clockwise, hence there is repulsion below the wire and attraction above it. The result of this magnetic drag is a clockwise rotation of the armature.

461. The E. M. F. of a Dynamo depends upon three things: speed, number of conductors, and number of lines of force cut. The relation in a two-pole dynamo is expressed by the formula

$$E = \frac{nCN}{10^8}, \tag{60}$$

in which n is the number of revolutions per second, C is the number of conductors on the armature, N is the number of lines of force in the magnetic circuit, and 10^8 is a constant necessary to reduce the product of nCN to volts.

The above formula is also applicable to the *back electromotive force* of a motor. By this is meant the E. M. F. that is generated in the armature of the motor because of the armature wires cutting the lines of force in its own field.

The existence of this back E. M. F. is shown by coupling a voltmeter to the terminals of a motor and sending current from a dynamo through the motor. The first reading of the voltmeter, before the motor starts, will be small and will be due to the potential drop caused by the resistance of the armature. As soon as the motor starts, the reading of the voltmeter begins to increase, and when the motor is running at its rated speed, the back E. M. F. is nearly as great as the E. M. F. of the dynamo. The voltage sending current through the motor is the difference between the E. M. F. of the dynamo and the back E. M. F. of the motor. This means that as the speed of a motor increases the current decreases.

An electric motor should be run from a current source having a constant electromotive force. From formula 60 we find the value of n to be $n = \frac{10^8E}{CN}$ which may be written, speed $= \frac{10^8E}{CN}$. Since E is constant and since C is also constant, as it is the number of conductors on the armature, it follows that if we wish to change the speed, it must be done by changing N, the number of lines of magnetic force in the field of the motor. Increasing the number of lines of force decreases the speed, and decreasing the number of lines of force increases the speed. This means that a motor runs faster with a weak magnetic field.

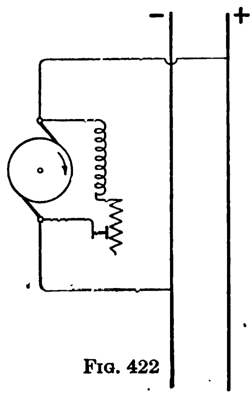


FIG. 422

This speed control is obtained in a shunt motor by putting a rheostat in series with the shunt field winding as shown in Fig. 422. In this way a wide range of speed can be obtained.

462. Thermoelectric Currents. — We have seen how an electric current is generated as a result of chemical action in a cell or battery (§ 377). We have studied also a second method of generating a current by the use of a generator or dynamo (§ 447). A third method is as follows:

Demonstration. — Twist together the ends of a small iron wire and a small copper wire and couple the other ends to the terminals of a sensitive galvanometer. Apply the heat of a Bunsen burner to the twisted ends of the wires and a movement of the galvanometer needle will indicate an electric current. Let the heated ends of the wires cool and the needle will return to zero. Hold a piece of ice against the twisted wires and the needle will move in the opposite direction.

The two wires as used in this demonstration form a thermoelectric couple. Such a couple will generate an electric

current as long as the twisted ends of the wires differ in temperature from the ends coupled to the galvanometer. An extensive use of this current is made in the thermoelectric pyrometer, which is valuable in various industrial operations.

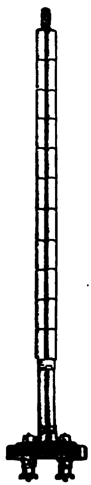


Fig. 423

When this instrument is used for temperatures not to exceed 1800° F. (982° C.) the wires are made of nickel alloys and the couple is called a base metal couple. The wires are welded together at one end and are separately inclosed in porcelain insulating tubes as shown in Fig. 423. When in use they are inclosed in an outer protecting tube.

For high temperatures the thermo-couple wires are one of platinum and the other of platinum alloyed with ten per cent of rhodium. This form can be used for temperatures as high as 2900° F. (1593° C.). High temperature pyrometers are used in measuring the temperature of furnaces, through the wall of which they are inserted.

The reading instrument is a form of millivoltmeter in which the scale is calibrated in degrees Fahrenheit or Centigrade as required. This instrument with its cover removed to show its interior construction is shown in Fig. 424.

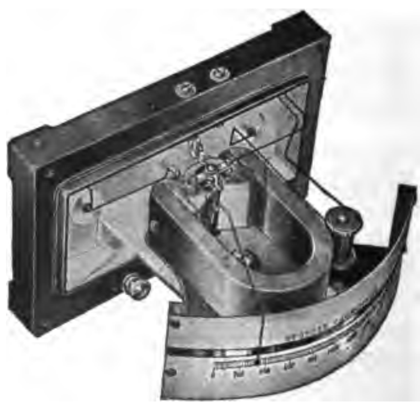


Fig. 424

Questions

1. If two wires of the spiral conductor in Fig. 387 are cut by a vertical plane, the directions of the magnetic lines of force are indicated by the dotted lines and arrowheads in Fig. 425. What law of magnetism will explain the action of the spiral?

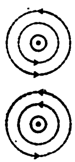


Fig. 425

2. If two parallel wires have currents going in opposite directions, one set of the lines of force will be reversed (compared with their direction in Fig. 425) as in Fig. 426. What will be the action of the conductors? How can it be explained?

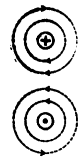


Fig. 426

3. In what ways can you produce an induced current? Suppose two coils with different numbers of turns are used to slip over the magnet in Fig. 393; how will the induced electromotive forces compare?

4. Explain the induced current in the secondary of an induction coil when the current is broken in the primary.

5. Examine Fig. 409 and show what part of the wire on the armature is inductor wire, that is, has an E. M. F. induced in it, and what part is merely a conductor. Explain.

6. What would be the effect of rotating this armature in the opposite direction?

7. What is the function of the iron core of the field magnet?

8. What effect will it have upon the voltage of a shunt dynamo to break the external circuit? Answer the same question concerning a series dynamo.

9. In an alternating current each change in direction of the current in a conductor is called an *alternation*. A *cycle* includes a current in both directions, so that there are two alternations per cycle. In a 2-pole machine there are two alternations per revolution. How many r. p. m. (revolutions per minute) must there be to give 25 cycles per second?

10. Suppose you wish to start a shunt motor at the lowest possible speed, would you have the resistance of the rheostat in Fig. 422 in series with the field or not?

11. Suppose you are running a lathe with a shunt motor and the handle of the rheostat is at about the middle point. Would you put in more resistance or less to increase the speed?

Problems

1. How many volts difference of potential will be generated in a wire if it cuts 950,000,000 lines of force per second?

2. If a 2-pole direct current generator is sending 75 amperes into its external circuit, how many amperes is each conductor wire carrying?

3. Answer problem 2 for an alternating current generator.

4. How many r. p. m. must a 4-pole machine have to give 60 cycles per second? How many alternations per second will such a machine give?

5. A 2-pole dynamo that generates 110 volts has 80 conductors on the armature and runs at a speed of 750 r. p. m. How many lines of force are in the magnetic circuit?

6. A dynamo gives 110 volts when it has 11,000,000 lines of force in its field. How many must it have to increase its voltage to 120?

VI. COMMERCIAL APPLICATIONS OF ELECTRICITY

463. The Telephone is an instrument used for the purpose of transmitting speech to a distance. The *receiver* of the Bell telephone is shown in section in Fig 427. *M* is a horseshoe magnet, around each pole of which a coil of fine wire is fixed. In front of the poles of the magnet a thin disk of iron *D* is fixed by its edge. Wires leading from the coils through the handle are fastened to binding posts *P*. When a current of electricity passes through the coils, it will change the number of lines of force going out from the poles of the magnet, and either increase or decrease the attraction the magnet has for the disk. If at the transmitting end of the line a person speaks into a similar instrument, the rarefactions and condensations of air produced by the voice will cause the disk to vibrate, thus making rapid changes in the distance of the disk from the end of the magnet, and

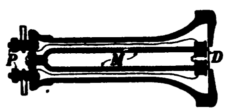


FIG. 427

these will induce currents in the coils. These currents coming to the receiver end, and passing through its coils, will set up similar vibrations in its iron disk, which will set up rarefactions and condensations in the air and thus reproduce the original sounds.

464. The Transmitter. — While the Bell receiver was originally used as a transmitter, many more efficient forms have been devised. Among these is the *solid-back transmitter*, shown in cross section in Fig. 428. The principle upon which this is made is that of the varying resistance of granular carbon produced by pressure upon it. The essential parts are the mouthpiece *M*, the metal case, the aluminum diaphragm *D*, the front terminal *F*, the back terminal *B*, and the granular carbon between the terminals. The terminals are connected with the primary of an induction coil in series with the line. A condensation of the sound wave entering the mouthpiece causes the diaphragm to compress the carbon granules; this reduces the resistance, and the current is increased. A rarefaction causes the diaphragm to lessen the pressure on the carbon; this increases the resistance, and reduces the current. These variations in the current respond with marvelous sensitiveness to the vibrations of the diaphragm and result in corresponding vibrations in the diaphragm of the receiving instrument, which is coupled in series with the secondary of the coil.

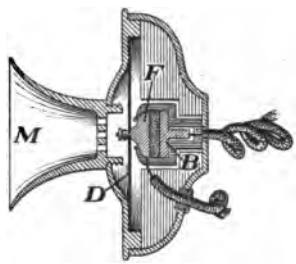


FIG. 428

465. Telephone Line Circuit.—One of the many ways in which a subscriber's instrument is coupled with a telephone line is shown in Fig. 429.

When the subscriber's receiver R is on the hook the current from B passes through an inductive resistance a, the line L', the storage battery D, the call bell C, the line L, the central station lamp, and the inductive resistance b, to the other side of the battery B. Since the resistance of the call bell is about 1000 ohms, the current is not enough to light the lamp. When, however, the receiver is taken from the hook, the secondary S of the induction coil, and the receiver in series with it, is put in parallel with the call bell. As this parallel circuit has a resistance of less than 50 ohms, the current is sufficient to light the lamp at central, signaling for the line. The slight current passing from B through the storage cells at D while the receiver is on the hook is sufficient to keep D fully charged, ready to send its current through the local circuit when the receiver is off the hook. The transmitter T is shown in series with the primary P of the induction coil.

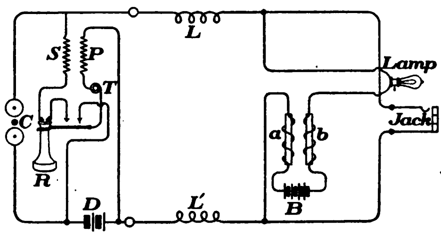


FIG. 429

Central calls the subscriber by closing the jack and cutting out the lamp, when the current will be large enough to ring the bell C.

466. Arc Lighting.—The simplest arc light is produced by sending a current of electricity from one carbon rod to another across a short air gap. To maintain the ordinary arc a difference of potential of from 45 to 50 volts is required, and this sends through the arc a current of from 9 to 10 amperes.

The + carbon is very much hotter than the − carbon, and as the current passes, the carbon becomes incandescent and some of it crosses the space between, forming a conductor for the current. This gives to the + carbon a cuplike shape in the middle, and this cup is the seat of the most intense artificial light and heat that have been produced.

A type of lamp much used in projection lanterns is the 90° angle lamp, one form of which is shown in Fig. 430. When used with the direct current the horizontal carbon is made the positive pole and its crater is kept in the axis of the lantern. The positive carbon wears away twice as fast as the negative, but both carbons can be kept in place as they wear away by being pushed forward by separate feeding screws. This form of lamp can also be used with the alternating current, in which case they are fed at an equal rate.

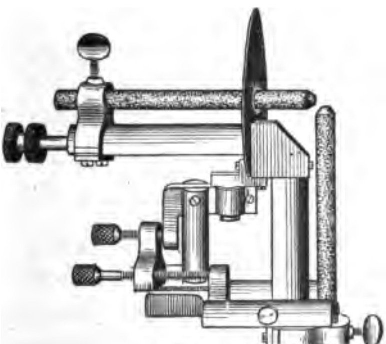


Fig. 430

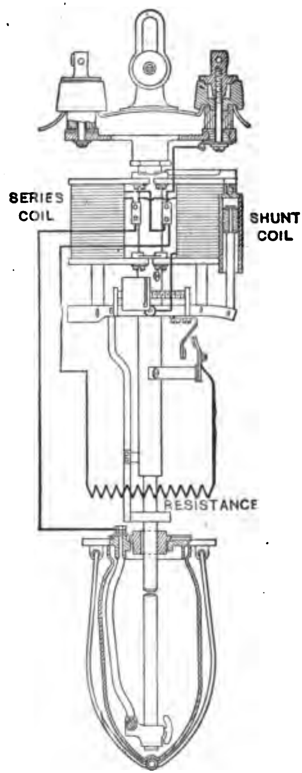


Fig. 431

467. The Inclosed Arc Lamp has a small globe nearly air-tight surrounding the arc and a few inches of the carbon. In this form of lamp the carbon is burned much more slowly than in the open arc, since the supply of air is cut off by the globe. Figure 431 is a diagram of the connections of

a direct current, series multiple arc lamp. The fall of potential across the arc is between 80 and 90 volts. A resistance is coupled in series with the arc so that the lamp can be used on a 110-volt circuit. There are two electromagnets that control the length of the arc. One is a series coil that lengthens the arc, and the other is a shunt coil that shortens it.

468. The Luminous Arc. — The ordinary carbon arc itself is not luminous, the light coming from the hot crater of the positive carbon. If, however, carbons are used which have a core made of a mixture of carbon and some metallic salts, the hot vapors given off by these salts become luminous when heated by the current. If calcium salts are used, the color is a golden yellow, and this arc is sometimes called the *flaming arc*, from its resemblance to a flame. The arc formed is much longer than the ordinary carbon arc and the light is exceedingly brilliant.

Another exceedingly brilliant source of light is the magnetite arc. This has a heavy copper rod for the positive upper terminal and a tube of sheet iron, packed with the mineral magnetite for the lower. The terminals wear away very slowly and the lamp is of high efficiency.

469. The Mercury Vapor Lamp. — When a tube, having a terminal at each end and inclosing a small quantity of mercury, is exhausted of air, the mercury vapor in the tube will carry the current when it is once started and it will become a source of light. In the Cooper-Hewitt lamp, Fig. 432, the mercury is held in the large bulb at one end of the tube and serves as the cathode. The anode is a small iron cup at the other end of the tube. Platinum wires sealed in the glass carry the current to the electrodes.

In the simplest form of the lamp the tube is tilted by pulling

on the suspended chain until the mercury runs through the tube in a thin stream. This mercury connects the electrodes and starts the current. As soon as there is a break in the stream, an arc is formed, the mercury vapor fills the tube and sustains the arc the full length of the tube when the mercury runs back.

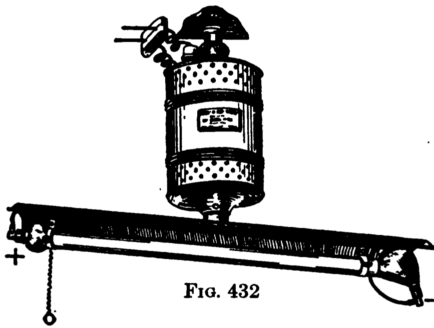


FIG. 432

The quality of the light is peculiar in that it contains no red rays. In uses in which the red rays are required, as in the judgment of colors, the lamp is supplied with a transforming reflector which converts a portion of the violet rays into red and improves the quality of the light for such purposes.

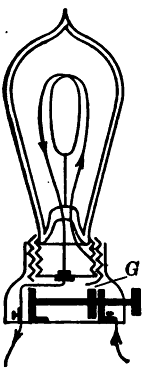


FIG. 433

470. Incandescent Lighting.—When a heavy current is sent through a small copper wire, the copper melts. If the same experiment is made with a platinum wire, the wire will not melt, but will become intensely hot, and glow with a very bright light. Similar *incandescence* can be produced also in some other substances. The incandescent lamp (Fig. 433) consists of a glass bulb, into the base of which there are sealed two platinum wires which carry a loop of carbon filament. The air is exhausted from the bulb before it is sealed. After the lamp is screwed into the base there is but one gap, in the circuit

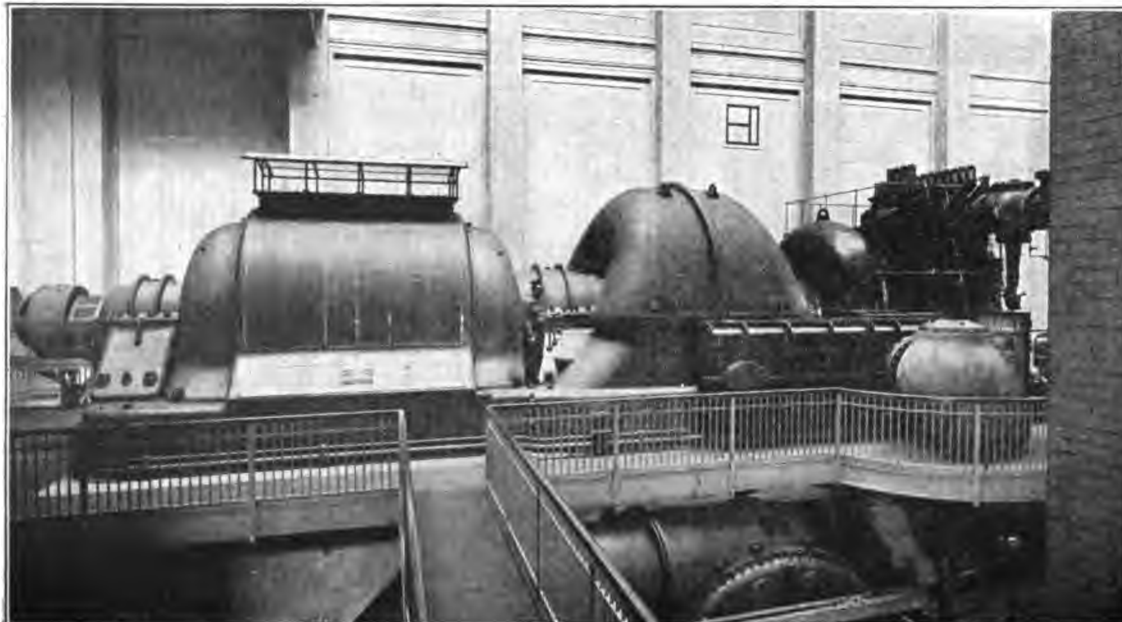


FIG. 434. — Turbo-Generator at the Schuylkill Station of the Philadelphia Electric Company

The capacity of this machine is 35,000 K.W., which means that it is capable of supplying energy for the total electrical demands of a city of about 125,000 population.

at G. This is closed when the lamp is turned on. When the proper current is sent through the carbon filament, it becomes incandescent, but does not burn, as there is no air in the bulb. After a lamp has been used for some time, part of the carbon becomes deposited on the inside of the bulb, and absorbs a great deal of the light sent out by the filament. When this has happened, the best economy is to replace the lamp with a new one.

471. Metallized Filaments. — If the carbon filament is "metallized" by subjecting it to the intense heat of an electric furnace, it is rendered much more *refractory*, that is, capable of being brought to a higher temperature without melting. The higher temperature causes the metallized filament to give out more light than the ordinary carbon filament for the same expenditure of electrical energy. A carbon lamp gives 16 candle power for about 50 watts, requiring 3.1 watts per candle power. The metallized filament lamp gives about 20 candle power for 50 watts, or 2.5 watts per candle power.

472. True Metal Filament Lamps of high efficiency have also been developed. These lamps depend upon the possibility of drawing certain of the less common metals, like tantalum and tungsten, into a flexible wire of very small diameter — 0.1 mm. or less — and also upon the ability of these wires to carry a current that brings them to incandescence without bringing them to the melting point. The tungsten lamp (Fig. 435) is of much higher efficiency than the carbon or metallized filament lamp. A 40-watt tungsten lamp will give 32 candle power or more, requiring less than 1.25 watts per candle power. This is most im-

FIG. 435

portant to the consumer, because what he pays for is watt hours and what he wishes to use is light, hence a tungsten gives him twice the returns that a metallized filament lamp gives.

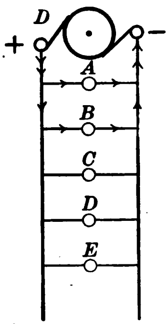


FIG. 436

473. The Incandescent Circuit. — Incandescent lamps are coupled in parallel across the mains, or wires leading from the dynamo. Figure 436 illustrates a simple incandescent circuit. The dynamo D is first run until its voltage is 110 volts, and then any lamp or group of lamps in the circuit can be turned on. The hot resistance of a 110-volt, 16-candle-power lamp is about 220 ohms; consequently each lamp requires a current of half an ampere. The parallel resistance of 2, 3, or n lamps being only $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{n}$th part of the resistance of a single lamp, the same dynamo that will light one lamp will light a number. If it were possible to build a dynamo without any internal resistance, the number of lamps that could be lighted would be very large. As this cannot be done, the number is limited. Several groups of wires are usually run from one dynamo. A group can be run from the mains at any point by coupling submains to them, that is, by attaching to each wire a branch wire large enough to carry the current for its group (Fig. 437). It is customary to put a fuse (Fig. 339) between each branch circuit and the main.

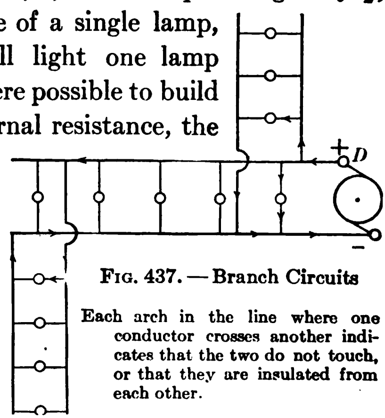


FIG. 437. — Branch Circuits

Each arch in the line where one conductor crosses another indicates that the two do not touch, or that they are insulated from each other.

474. The Three-wire System. —In order to reduce the expense of distribution, Edison devised the three-wire system, in which two similar dynamos D, D' are coupled in series (Fig. 438). The main feeding wires are attached one to the positive of the first dynamo, and the other to the negative of the second. A third wire is attached to the negative of the first and to the positive of the second dynamo. If there are equal numbers of lamps burning on both sides of the middle wire, it will carry no current, but if there are 50 lamps on one side and 55 on the other, for instance, it will carry the current for 5 lamps. The middle or *neutral* wire is often grounded.

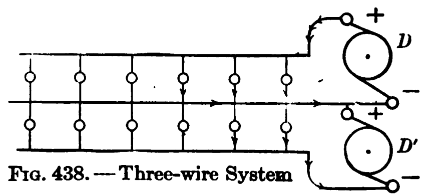


Fig. 438. — Three-wire System

475. Alternating Current Transformer. — Since alternating dynamos are built to give high voltage, some method is necessary for changing this voltage to that which can be used in a lamp. A *step-down transformer* is used for this purpose; it is virtually a reversed Ruhmkorff coil, — reversed because the work to be done is to change a high potential current into one of a low potential. The principle of the step-down transformer is shown in Fig. 439. The current from the dynamo flows through a long coil of fine wire which has an iron core to increase the magnetic field. Surrounding the same core is a second coil, shorter and of larger wire. To the terminals of this coil are attached the lamps to be lighted. The proper size and

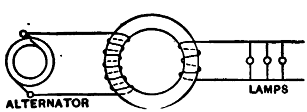


Fig. 439

length of the wire in each coil are determined by the respective voltages of the dynamo and of the lamps to be used. A step-down transformer reduces the voltage in the same ratio as that of the numbers of turns in the two coils. For instance, to reduce a 1000-volt current to one of 100 volts, the number of turns in the primary must be 10 times the number in the secondary. Very little energy is lost in the transformation; if the 1000-volt current sent into the transformer is of 1 ampere, the 100-volt current taken from it will be of very nearly 10 amperes.

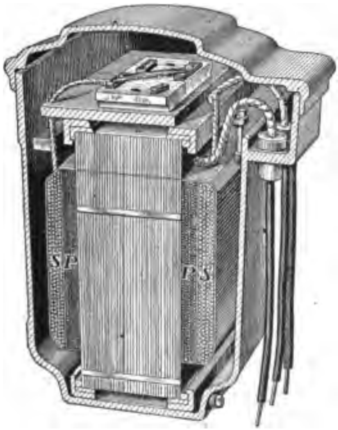


FIG. 440

Figure 440 shows in cross section the details of a step-down transformer with the relation of its parts, *P* being the windings of the primary coil and *S* of the secondary; and Fig. 441 shows the instrument as set up for use. This is the kind used on a line pole to reduce the 1000-volt current from the station to a lower voltage current for house use. When in use, it is filled with oil for insulation.

A *step-up transformer* changes a current of low voltage to one of high voltage; it has a greater number of turns in the secondary than in the primary.


FIG. 441

476. Electric Railways. — The trolley lines and third-rail railways of the United States have for their essential parts

the generating stations and generators, feed wires, trolley wires or third rails, the cars, and the road bed. The generators are usually direct-current dynamos producing current

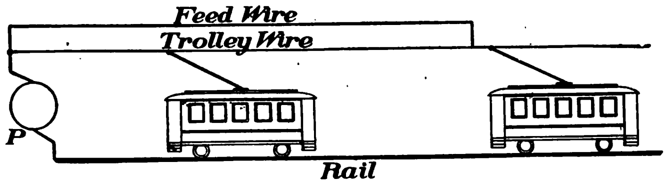


FIG. 442

at a pressure of about 500 volts. The positive poles of these dynamos are connected to the feed wires, trolley wires, or third rails, while the negative poles are connected to the rails, which serve as return conductors.


FIG. 443. — Trolley Car Motor, with case opened

Feed wires are used when the line is a long one; they are connected to different sections of the trolley wire. The current goes from the trolley wire to the wheel in contact with it, down the conductor carried by the pole, to the motor, then through the car wheels to the track and then to the dynamo. The cars are in parallel, like incandescent lamps on a lighting circuit, and each takes its own current, independent of the rest. The amount of current taken by each car depends largely upon the load in the car and the grade of the road. Since the motors are

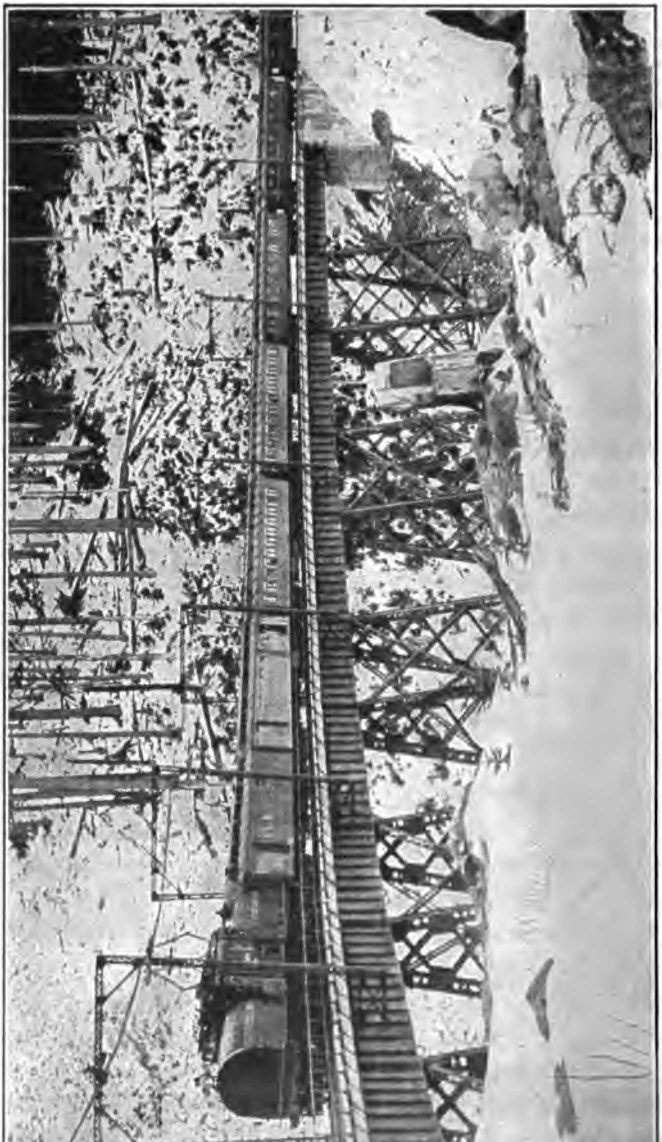


FIG. 444. — Electric Locomotive and Transcontinental Passenger Train in the Cascade Mountains

subject to the severest kind of usage, they are protected with water-tight cases.

Hundreds of electric railways transport people to and from their places of business in large cities. Figure 444 shows a transcontinental passenger train on an electric railway. Another important use of motors is their application to individual machines such as printing presses, lathes, band saws, etc. Each machine can then be run separately without large waste of power through the friction of shafts and belting.

477. The Transmission of Electrical Energy.— The function of a transmission line is to transmit electrical energy to a distance. There is always a certain loss in transmission, due chiefly to the heating of the line. As the heating of a conductor is proportional to the square of the current, it is plain that the current sent should be as small as possible. To transmit 10,000 watts of electrical power by using 1 ampere at a pressure of 10,000 volts is much more economical than to send 10 amperes at a pressure of 1000 volts. For this reason transmission lines are high tension lines, and require only a small wire to carry the current.

For instance, the alternators of the electric road from Philadelphia to Atlantic City give 6600 volts, but this current is changed to one of 33,000 volts by the use of step-up transformers. It is sent over the line at this voltage to the substations where the voltage is reduced to 430 volts by step-down transformers and then fed into the alternating side of a rotary *converter*, from the direct current side of which a direct current of 650 volts is taken. This is fed into the third rail which feeds the motors on the cars.

478. Electric Welding. — The heating effect of the current is used effectively in electric welding. For this purpose heavy currents are used, such as are supplied from the low-voltage side of a step-down transformer. The reason for this may be seen from a review of section 402.

Demonstration. — Couple two insulated copper bell wires to a 110-volt circuit in series with a 110-volt lamp; hold them touching end to end. The current passing through the high resistance of the junction of the two wires will produce so great heat that the ends will melt and on being pushed together the wires will become welded and form a single conductor.

This is an example of what is known as resistance welding. The pieces to be welded are held together end to end and when the metal becomes plastic the ends are pushed together and the current turned off. Special machines are used to perform these operations in regular succession.

Another type of electric welding, called spot welding, is used to weld one sheet of metal to another. Two large electrodes are used to press the metal surfaces together and to localize the heat of the current. These electrodes are shown at E in Fig. 445. The pieces to be welded are placed between the electrodes and on pulling down the lever L or pressing down the treadle T the pressure is applied and the current turned on for the few seconds necessary.

FIG. 445. — Spot-welding Machine

Another form of welding, called seam welding, makes use of the great heat of the electric arc.

Questions

1. Make a drawing showing how the lines of force go through the diaphragm of a telephone receiver.

2. How do you explain the heavy current that passes through the carbons of an arc lamp when the lamp is first turned on?

3. Why is platinum used instead of copper for the sealing-in wire of incandescent lamps?

4. Why is it a good plan — whenever a dynamo supplies current to a number of groups of lamps — to place a fuse between each group and the mains?

5. Why is it necessary to use a step-down transformer between the street mains of an alternating system and the house lighting?

6. Why is it best to use a step-up transformer between the alternating current generator and the transmission line?

Problems

1. A small arc lamp requires a current of 4 amperes and a difference of potential at its terminals of 45 volts. What is the resistance of the lamp? What resistance must be put in series with it on a 110-volt circuit?

2. An open arc requires a voltage of 45 volts and a current of 9 amperes. What is the resistance of the arc? How much resistance must be put in series with the arc to burn it across a 110-volt circuit? How much must be put in if two arcs are put in series across this circuit? How much current will they take?

3. The positive carbon of a projection lantern (§ 466) burns off an inch in length in 40 minutes. How much will each carbon be shortened if the lantern is run for a lecture lasting an hour and a half?

4. A projection arc lamp that takes 10 amperes at a voltage of 55 volts, is sometimes run on a 220-volt circuit for the purpose of getting a steadier light. What resistance must then be placed in series with it?

5. Twelve open arc lamps, each requiring 50 volts and 9.6 amperes, are coupled in series and run by a dynamo. How many volts must it give? How many amperes? What is the resistance of the 12 lamps in series? What resistance must be put in series with them to reduce the current to 9 amperes?

6. A certain inclosed arc lamp requires 4.5 amperes, but the voltage at its terminals must be 80 volts to run it properly. What is the resistance of the inclosed arc lamp? How much resistance must be put in series with it to burn it across a 110-volt circuit?

7. What must be the resistance of the heating coil of a trolley car so that the current shall be 75 amperes on a 550-volt circuit? Find the number of watts.

8. The searchlight projector at Fort Monroe has a diameter of 60 inches. With 150 amperes at 60 volts the arc gives 194,000,000 candle power. What is the resistance of the arc? How many candle power does it give per watt?

9. A D.C. flaming arc lamp is run on a 115-volt circuit and requires 6.5 amperes. The arc itself takes 70 volts. Find the terminal watts, the arc watts, the resistance of the arc, the resistance in series with the arc, and the efficiency of the lamp.

10. How much current is required by a 40-watt Mazda lamp run on a 110-volt circuit? How much is required by a 60-watt lamp on the same circuit?

11. Suppose 15 of the 40-watt lamps of problem 10 are burning on one side of the neutral wire in a 3-wire system, and 12 of the 60-watt lamps on the other side. How much current is the wire on the 40-watt side carrying? How much is the wire on the 60-watt side carrying? How much does the neutral wire carry?

12. Mazda B lamps for electric railway service are run 5 in series on a 550-volt circuit. How many volts does each lamp require? How many amperes if they are 36-watt lamps? What is the resistance of each lamp? How much heat does each lamp give to the car per minute?

13. How many amperes are required in an electric furnace that runs on a 70-volt circuit and uses 9 kilowatts?

14. To weld an average sized rail bond to a rail requires 2000 amperes at 5 volts. Find the resistance of the joint. How many calories per minute are developed?

15. A 1000-volt current of 3 amperes is sent through the primary of a transformer having an efficiency of 97 per cent. How many 104-volt lamps can it light if each requires 0.52 ampere?

16. On the first floor of a house 12, 40-watt, Mazda (tungsten) lamps are used. On the second floor 18, 25-watt, lamps of the same kind are used. How much current will be required to run all the lamps at the same time, if they are run on a 110-volt circuit?

CHAPTER X

LIGHT

I. NATURE AND INTENSITY OF LIGHT

479. Light is the form of radiant energy which, by its effect upon the retina, excites the sensation of vision. There are many reasons for supposing that this action is a vibration of the ether (§§ 271, 272). This vibration, unlike sound vibration, is transverse, — that is, perpendicular to the direction in which the light is moving.

Luminous bodies are those that emit light. The term is usually applied to those bodies only that are *self-luminous.* When light falls upon a body, part of it is reflected; part is absorbed by the body, changing the molecular or atomic force; and part may or may not pass through the body. *Transparent bodies* are those that permit light to pass through them in such a way that objects are distinctly visible through them. When light comes through a body as diffused light, and objects cannot be distinctly seen through it, the body is called *translucent.* If the body does not permit light to pass through at all, it is called an *opaque* body.

The classification of bodies as opaque and transparent is not very accurate, for thick layers of transparent bodies absorb a great deal of light, while thin layers of opaque substances are sometimes transparent.

Demonstration. — The transparency of gold leaf can readily be shown by laying a piece of gold leaf upon a glass plate and covering it with another plate of the same size. It is well to bind these together with a strip of gummed paper such as is used in making lantern slides. Hold the plates close to the eye and objects can be seen clearly through the gold leaf. Compare the color of the transmitted light with the color that is reflected from gold.

480. The Propagation of Light. — A luminous *ray* is a single line of light propagated from a luminous point. It is always perpendicular to the front of the advancing light wave, and in the case of a spherical wave is a radius drawn from the source of light. A group of rays from the same source is a *pencil* of rays. If these rays are parallel, they constitute a *beam* of light. If they diverge from a point, they form a *diverging* pencil. If they meet at a point, they form a *converging* pencil.

In a homogeneous medium, *the direction of propagation of light is in straight lines.* But light is affected by gravitation; thus when the ray from a star passes near the sun it is bent slightly towards the sun out of its straight-line path, to the extent predicted by Einstein.

481. Umbra and Penumbra. — **Demonstration.** — Select a board about 2 ft. long and 8 in. wide, and set up in the middle of it a wooden cylinder 2 in. in diameter and 5 in. high. Fasten an upright 6 in. high to one end of the board and near the other end set up two candles 4 in. apart. Observe the shadows cast by the cylinder upon the upright.

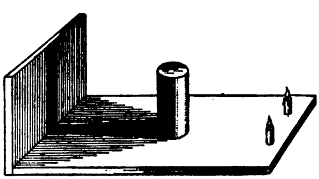


Fig. 446

The dark part where the shadows overlap is the *umbra,* and the part which is lighted by only one candle is the *penumbra.* When a single source of light is so small as to

be considered a point, the shadow is all umbra. If the source of the light is larger, the umbra is partly or completely surrounded by a penumbra. Figure 447 illustrates the case in which the light comes from a luminous ball and the opaque body is a larger ball. If L is the luminous and B the opaque ball, a screen S will show the existence of a circular umbra or shadow whose limits can be determined by moving a straight line around both balls and tangent to both of them

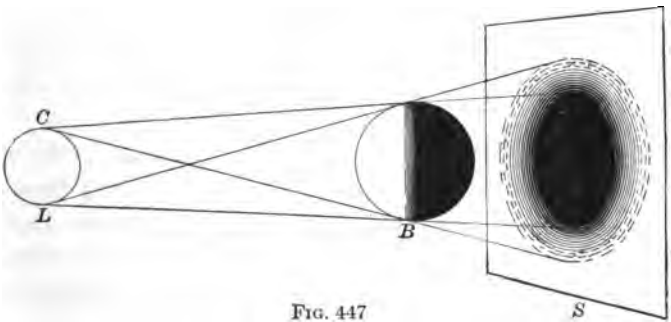


FIG. 447

on the same side, as LB. There will be a penumbra, however, entirely around the umbra; this will extend to the limits of a circle marked by a line tangent to both balls, but always on opposite sides of them, as CB. At the edge of the umbra the penumbra will be nearly as dark as the umbra, and it will gradually grow lighter and lighter toward the outer edge. The moon is much smaller than the sun, its diameter being 2163 miles, but its distance from the earth is so much less, that it appears to be of nearly the same size. In its journey around the earth the moon sometimes comes between us and the sun and acts as a screen, cutting off the sun's light from us. If the observer is at a part of the earth where the light of the sun is entirely cut off, as in the

umbra of Fig. 447, the eclipse is total. If he is where a portion of the sun can be seen, he is in the penumbra and the eclipse is partial, as in Fig. 448.

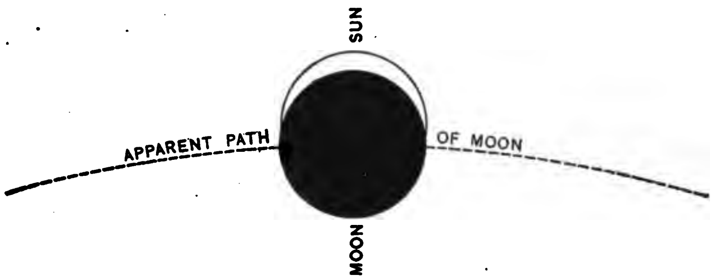


FIG. 448

482. The Formation of Images. — An image is the picture of an object formed by rays of light coming from it. The image formed by rays passing through a small opening is always inverted. That this must be so is shown by a study of Fig. 449, which illustrates the formation of an image by a

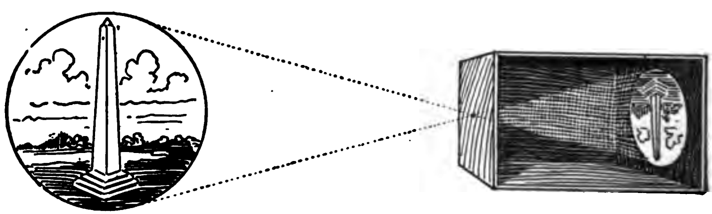


FIG. 449

pinhole camera. Since all the light that forms the image comes through the pinhole, all the rays that are not parallel must cross in passing through it. The ray coming from the top of the object forms its image at the bottom. The ray from the bottom of the object goes to the top of the image. The ray from the right side strikes the left, etc. Hence there is a complete reversal in the image.

If a room is darkened and sunlight is let into it through the side of a Venetian blind, a series of sun images will be formed on the walls or floor wherever the light falls. If sunlight comes through a dusty window pane into a darkened room, the lighted part of the wall opposite is made up of a number of overlapping images of the sun. In partial eclipses of the sun, the light coming through small openings in the leaves of trees will form inverted crescent images of the sun on the ground.

483. The Velocity of Light was long thought to be instantaneous. In 1675, however, Römer, a Danish astronomer, determined the velocity of light by a study of the satellite of Jupiter.

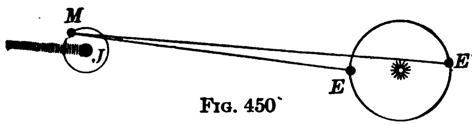


FIG. 450

One of the moons of Jupiter, in its path around the planet, passes into the shadow of the planet once in 42 hr. 28 min. and 36 sec., on the average. Römer noticed that while the earth was passing from E to E' the observed times of the eclipses were later than the computed times, and that the differences between them kept increasing until, after six months, at E', the total retardation was 16 min. 36 sec. This means that it takes the light 16 min. 36 sec. to cross the orbit of the earth, about 196,000,000 miles. This gives a velocity of about 186,000 miles or 300,000 km. per second.

The determination has been made in other ways, and the results confirm Römer's measurement. The velocity is so great that light could travel around the earth nearly $7\frac{1}{2}$ times in 1 second.

484. The Intensity of Illumination is measured by the quantity of light that falls on a unit of surface. This differs with the intensity of the source of the light, and with the distance from the source.

The intensity of illumination upon any surface is inversely proportional to the square of its distance from the source of light. This law is true for very small sources of light only. It can be verified as follows:

Demonstration. — Place a lamp close to a screen through which there is a small hole. At a distance of 1 ft. place a cardboard disk

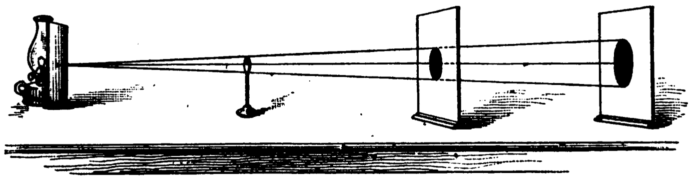


FIG. 451

1 in. in diameter. Place a screen 2 ft. from the light, and the shadow cast by the disk will be 2 in. in diameter, and its area four times that of the disk. Since the disk cuts off the light from a part of the screen four times as great as itself, the intensity of the light falling upon the screen must be only one fourth as great as that falling upon the disk. If the screen is placed three feet from the light the intensity will be only one ninth as great.

485. Photometry is the process of measuring the relative intensities of light. The instruments used for the purpose are called photometers. The practical working standard of intensity is the incandescent lamp. This is first standardized in terms of candle power based upon the light given by a sperm candle, and after being "seasoned" by use gives a nearly constant candle power. From tests made at the Bureau of Standards at Washington the average candle power of carbon filament lamps with a current of 0.5924 ampere was 16. The 25-watt tungsten lamp gives 20 candle power and the Welsbach mantle lamp under good gas pressure, 50 candle power or more.

486. The Bunsen Photometer consists of a screen of unglazed white paper having in the middle a spot of paraffin or oil. It is sometimes called the *grease spot* photometer. Figure 452 shows the arrangement of the spot box with two mirrors M and M' so inclined that the two images of the spot

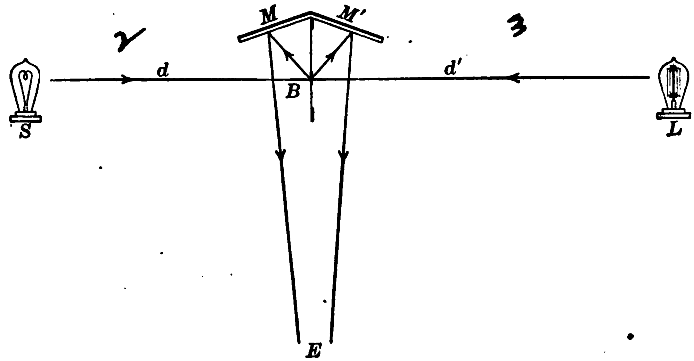


FIG. 452

will be seen side by side. The sources of light to be compared are placed one on each side of the screen and at such distances that the spot is invisible. This takes place when the same amount of light strikes upon each side of the screen, from the two light sources. Applying the law of light intensity we have from Fig. 452

$$S : L = d^2 : d'^2,$$

hence

$$L = S\frac{d'^2}{d^2}. \tag{61}$$

487. The Joly Photometer. — One of the simplest photometers to make is the Joly, which consists of two square pieces of paraffin with a piece of tin foil between them. If this is used in place of the spot box of the Bunsen photometer, the two sides will be equally lighted and appear equally bright when $S : L = d^2 : d'^2$ as before.

Questions

1. Would a perfectly transparent body be visible?

2. What do we assume concerning the propagation of light when we aim a gun?

3. Show by a figure the relative positions of the sun, earth, and moon when there is (*a*) a total eclipse of the sun; (*b*) a partial eclipse of the sun; (*c*) a total eclipse of the moon.

4. What shapes of shadow can a disk give upon a screen? What is the only shape of shadow a sphere can give? Why? What suggestions, in these answers, of a way to prove the shape of the earth?

5. Occasionally a "new star" is seen in the heavens. Did the phenomena that make it visible take place recently or long ago?

Problems

1. A box 1 ft. square has a small hole in the middle of one side and a ground-glass plate for the opposite side. What is the length of the image formed on the ground glass, of a window 5 ft. high, at a distance of 12 ft. from the hole in the box?

2. A pinhole image of a house is 5 in. high, the screen is 8 in. from the pinhole, and the house is 100 ft. from the camera. How high is the house?

3. The moon is 238,840 mi. from the earth. How long after its edge comes between the earth and the sun does the eclipse begin to be seen?

4. If the sun were suddenly extinguished, how long before its light would cease to reach the earth?

5. If the distance from the earth to Jupiter is 390,000,000 mi., how long after one of Jupiter's moons passes into the shadow of the planet is the eclipse observed on the earth?

6. Alpha Centauri, the nearest of the fixed stars, is not less than 20,000,000,000,000 miles from the solar system. About how many days does it take for the light to come from the star to the earth?

7. If a 16-candle-power lamp is 1.3 m. from a Bunsen photometer screen, how far must a 20-candle-power lamp be on the other side when the spot box is properly adjusted?

8. How far must an 800-candle-power arc lamp be from the same screen for equal illumination?

9. What is the candle power of a lamp that gives the same illumination at a distance of 5.2 m.?

10. The two sides of a Joly screen appear equally bright when placed 3 ft. from a kerosene lamp and 5 ft. from an incandescent lamp. How do the lamps compare in the amount of light given out?

II. THE REFLECTION OF LIGHT

488. Reflected and Diffused Light. — Whenever light strikes upon a highly polished surface, the greater part of the light will be reflected regularly, a parallel beam being reflected as a parallel beam. If, however, the surface is not polished, the reflected rays are not parallel but are scattered, and diffused light is the result. Bodies that are not self-luminous are made visible by the light which they diffuse. A perfectly reflecting surface is invisible.

Demonstration. — Let a beam of sunlight strike upon a mirror and it will be reflected, giving a brilliant spot of light upon the wall. Replace the mirror by a sheet of plain white paper and the light will be scattered or diffused. Each ray of light is reflected according to the law of reflection, but the unevenness of the surface of the paper causes the reflected rays to scatter in various directions, as shown in Fig. 453.

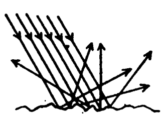


FIG. 453

489. Reflection. — **Demonstration.** — Through a small hole in the shutter of a darkened room admit a ray of sunlight. Lay a mirror in its path and scatter crayon dust or smoke in the air. A large part of the light is reflected. Observe that the reflected ray is straight and that its direction depends upon the angle at which the ray strikes the mirror.

In Fig. 454, if L is the source of light, MM' the reflecting surface, P the point at which a ray of light strikes it, and

PH the *normal* or perpendicular to the reflecting surface at the point *P*, then *LP* is called the *incident ray*, *PB* the *reflected ray*, the angle *LPH* the *angle of incidence*, which is the angle between the perpendicular *HP* and the incident ray, and *BPH* the *angle of reflection.*

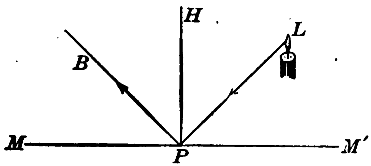


FIG. 454

490. The Laws of Reflection.

I. *The angle of reflection is equal to the angle of incidence and is in the same plane.*

II. *The plane including the incident and reflected rays is perpendicular to the reflecting surface.*

491. The Hartl Optical Disk is so well adapted to the demonstration of the fundamental phenomena of light, that its use is recommended for class demonstrations. A dark room is not necessary, as the disk will show the phenomena in an ordinary room. Sunlight is the best source of light to use with it, but an arc lamp, an incandescent lamp, or a mantle lamp will do.

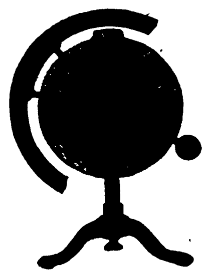


FIG. 455

Demonstration. — Figure 455 shows the apparatus in use to demonstrate the laws of reflection from a plane mirror. The graduated scale and the semicircular sheet-metal screen are capable of rotating independently on the same axis. On sending a beam of sunlight through the opening in the screen, letting the smaller beams strike upon a mirror fixed to the disk, and turning the disk until the beams strike at an angle to the zero line, it will be seen that the reflected beams make the same angle with the zero line, or normal, that the incident beams make with the same line.

492. Plane Mirrors and their Images. — A plane mirror is a plane surface that reflects regularly a large part of the light that falls upon it. If a person stands in front of a plane mirror, he sees his image apparently behind it. If he walks toward the mirror, the image does the same. If he steps to one side, the image does also. If he looks at the image of a stationary object, it remains in the same place however much he changes his position. This kind of image is called a *virtual image* because it does not really exist at the place where it appears to be, but is caused by divergent rays of light that come from the object and are reflected from the mirror.

493. To locate the Image of a Point. — Let A (Fig. 456) be the point, the image of which is to be found. Since the angle of reflection is equal to the angle of incidence, the ray AB, perpendicular to the surface, will be reflected upon itself in the direction BA; and the image of the point A will be on BA or AB prolonged. Any other ray AC will be reflected as CE, making the angle of reflection ECD equal to the angle of incidence ACD; and the image will be on CE or EC prolonged. As the lines BA and CE are divergent in front of the mirror, their only point of intersection is at A', a point behind the mirror, which is the image of A.

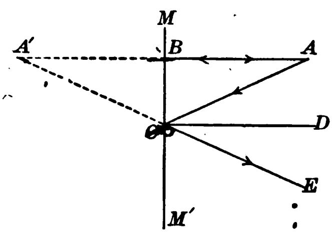


FIG. 456

From the figure the triangles ABC and $A'BC$ are right triangles, and the line BC is common. The angles ACB and ECM' are equal, since $ECD = ACD$. But $A'CB$ also equals ECM'; hence the angle ACB equals the angle $A'CB$, and the

triangles ABC and $A'BC$ are equal in all their parts. Hence $A'B = AB$. This means that *the image of a point in a plane mirror is on a perpendicular from the point to the mirror and as far behind the mirror as the object is in front of it.*

494. To locate the Image of an Object. — If the object is a straight rod like the arrow AB in Fig. 457, it will be necessary to determine the position of the image of each end, only as all intermediate points will be found on the straight line which joins them. The points A' and B' are found by § 493. The paths taken by the rays that enter the eye at E may be shown by finding the points C and D, where straight lines from the points A' and B' to the eye intersect the mirror. The incident rays, then, will be AC and BD, and the reflected rays will be CE and DE. When the eye is at E, the only part of the mirror used is CD. An eye placed at E' would see the image likewise at $A'B'$, but would use an entirely different part of the mirror.

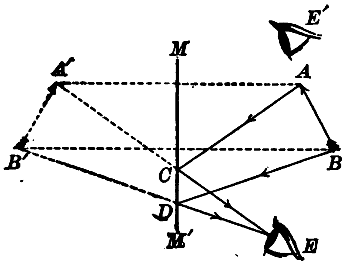


FIG. 457

Demonstrations. — Place a mirror horizontally on a table and look at the image of a candle placed the other side of the mirror from the eye. What kind of inversion is caused by a horizontal mirror?

Stand at a distance in front of a small plane mirror placed *vertically* against the wall. Notice how much of your figure you can see; then walk toward the mirror, and observe whether any greater length of the figure can be seen. Explain.

Stand in front of a plane mirror with the right hand raised. Which hand of the image is raised? What kind of inversion is caused by a vertical mirror?

495. Multiple Images from Mirrors at an Angle. — If two mirrors are placed at a right angle with each other, as M and M' (Fig. 458), the object being at A and the eye at E, then there will be seen an image A' in the mirror M, a second image A'' in the mirror M', and a third A''', which is the image in M' of the image A' formed by the mirror M. The positions of all these images may be found by applying the rule for finding the image of a point in a plane mirror (§ 493). The paths of the rays that enter the eye may be found as is shown in the figure.

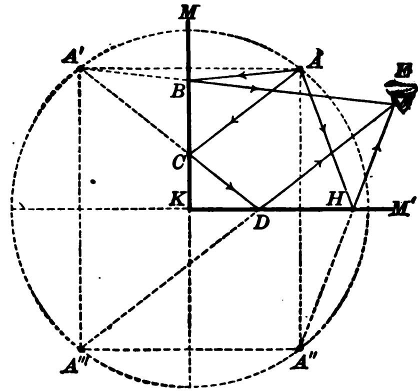


FIG. 458

Multiple images formed in two mirrors that are inclined at a less angle than 90° can be studied by a pair of hinged mirrors, such as are shown in Fig. 459. By standing the mirrors on a table and varying the angle between them, the relation between the angle and the number of images can be shown.

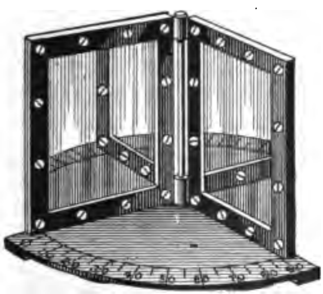


FIG. 459

496. Multiple Images from Parallel Mirrors. — If two mirrors MM' and NN' are placed parallel and facing each other, several images of the candle C will be seen by the eye E,

placed as in Fig. 460. What may be called primary images, formed by one reflection, will be seen in the directions EA

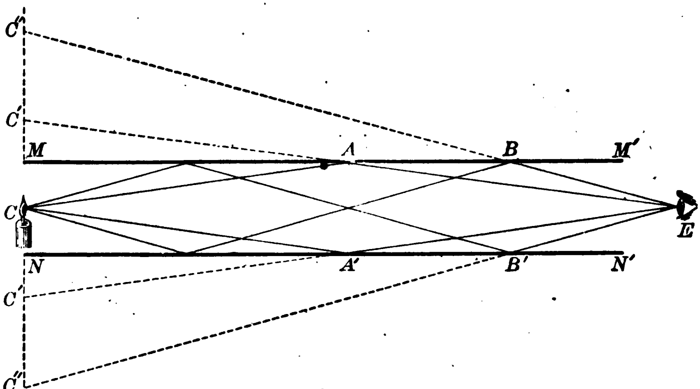


FIG. 460

and EA'. Secondary images, formed by two reflections, will be seen in the directions EB and EB'. The images of the candle appear at C' and C''.

Demonstrations. — Place four long, narrow strips of mirror inside a long narrow box, fastening them to the four sides. Make a cover for one end and bore a small hole in the middle of it. Place the eye at the opposite end of the box and direct the box toward a window. Observe the different images seen from the four sides. Strips of window glass backed with black paper will do very well if mirrors cannot be obtained.

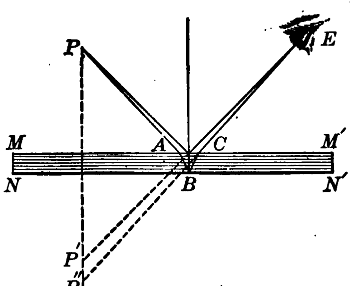


FIG. 461

497. Multiple Images formed by a Plate-glass Mirror. — When light from any source, as the point P (Fig. 461), falls upon a

plate-glass mirror, two images will be formed: one at P' from the upper surface MM', and one at P'' from the lower surface NN'. The image P' is generally faint, as but little of the light striking MM' is reflected from that surface, the most of it passing through to the surface NN', from which, as the glass has a mercury back, it is nearly all reflected. The reason for the bending of the ray at A and C will be explained under the subject Refraction.

By holding a lamp close to a plate-glass mirror and looking at its image in a slanting direction several images will be seen. Two of these are like P' and P'' (Fig. 461); the others are due to rays striking the mirror at the left of A and emerging at the right of C after several reflections between NN' and MM'.

498. Concave Mirrors may be formed of the concave surfaces of either spheres or paraboloids, hence the sections of concave mirrors by a plane will be arcs of either circles or parabolas. If C is the center of the sphere from which the mirror in Fig. 462 is formed, and MN the section of the mirror, then C is the *center of curvature*, A is the *center of the mirror*, CA is the *principal axis*, any other axis, as EB, is a *secondary axis*, and MCN is the *aperture* of the mirror. In the treatment which follows (§§ 499–505), the aperture of the mirror is supposed to be not more than 10° or 12°, but in order to construct the geometrical figures clearly it is taken much greater.

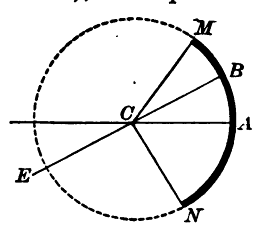


FIG. 462

499. Foci. — A *focus* is a point to which rays of light converge, or from which they diverge. The *principal focus* of a mirror is the point, on the principal axis, in which rays of light parallel to that axis meet after being reflected

from the mirror. The distance of this point from the mirror is the *principal focal length.* A focus is *real* when it is caused by the meeting of rays of light, and *virtual* when rays appear to come from it.

500. Foci of Concave Mirrors. — There are six cases that can be considered.

(*a*) *When the Source of Light is at an Infinite Distance.* — In this case the rays of light will be parallel to the principal axis. The direction of the reflected ray MF (Fig. 463) is determined by drawing the normal from M to the center of curvature C, and making the angle of reflection CMF equal to the angle of incidence CMD. This reflected ray will cut the principal axis in F, a point practically halfway between C and A. By a similar construction it can be shown that other parallel rays will pass through F; hence F is at the *principal focus.*

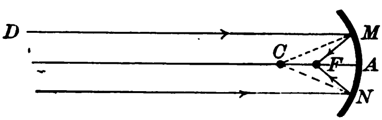


FIG. 463

(*b*) *When the Source of Light is at a Finite Distance beyond the Center of Curvature.* — In this case the rays of light will diverge, as from the point P (Fig. 464). The direction of any ray, as PM, after reflection is found by making the angle CMP' equal to the angle CMP. Other rays from P striking the mirror will, after reflection, meet at P', which is a point between the center of curvature and the principal focus.

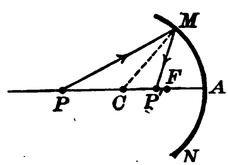


FIG. 464

(*c*) *When the Source of Light is at the Center of Curvature.* — Since every line from the center of curvature to the

mirror is a radius of the mirror, it is evident that the focus will be found at C.

(*d*) *When the Source of Light is between the Center of Curvature and the Principal Focus.* — This is the converse of case (*b*), and by reference to Fig. 464 it will be seen that the focus of P' is P, a point beyond the center of curvature.

(*e*) *When the Source of Light is at the Principal Focus.* — This is the converse of case (*a*). When the source of light is at F (Fig. 463), the direction of every ray after reflection will be parallel to the principal axis; that is, the focus will be at an infinite distance — in other words, there will be no focus.

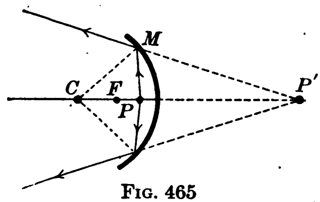


FIG. 465

(*f*) *When the Source of Light is between the Principal Focus and the Mirror.* — By making the angle of reflection equal to the angle of incidence CMP (Fig. 465), it will be seen that the reflected rays diverge from the principal axis as though they came from a point P' behind the mirror. This point P' is a *virtual focus*.

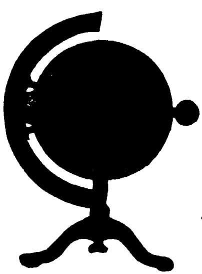


FIG. 466

Demonstration. — By allowing parallel rays of light to fall upon the screen of the optical disk, the location of the principal focus of a concave mirror can be readily seen. The principal focal length is practically half the radius of the mirror.

501. Focus of a Point not in the Principal Axis. — If the source of light is not in the principal axis, its focus may be found by the following simple construction. Draw from the

point P (Fig. 467) a secondary axis through C. The ray sent in this direction will be reflected on itself. Draw a ray parallel to the principal axis, as PM. It will be reflected through F, and its intersection with NC will determine the point P', the focus of rays coming from P.

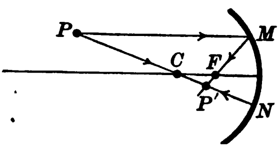


FIG. 467

502. Conjugate Foci. — By a study of the relation between the position of the point of light and its focus it is seen that in all cases in which there is a real focus, the point of light and its focus, or image, are interchangeable. If a candle is used at P, its image is found at P'. If now the candle is placed at P', its image is at P. Two points, so located that one is the image of the other, are *conjugate foci.*

503. Images formed by Concave Mirrors. — The geometrical construction of images formed by concave mirrors is practically the determination of the foci of points. To make this construction but two rays are necessary for each point, since the intersection of any two reflected rays determines the image of a point. By using the ray passing through C, which is a secondary axis, and the ray parallel to the principal axis, only three lines need be drawn.

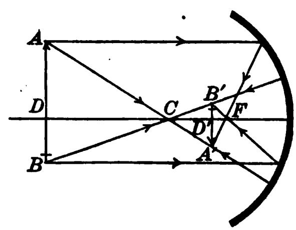


FIG. 468

(*a*) *When the Object is at an Infinite Distance.* — Since the focus of rays parallel to the principal axis is at the principal focus, the image will be at F, and will be a point.

(*b*) *When the Object is at a Finite Distance beyond the Center of Curvature.* — Following the rule for construction

given above, the points A' and B' (Fig. 468) are found. These being the extreme points of the image, all other points lie between them. The image is real, inverted, smaller than the object, and between the center of curvature and the focus.

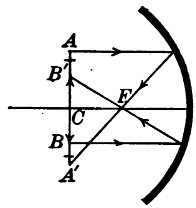


FIG. 469

(c) *When the Object is at the Center of Curvature.* — In this case, Fig. 469 shows that the image will be real, inverted, of the same size as the object, and at the center of curvature.

(d) *When the Object is between the Center of Curvature and the Principal Focus.* — This is the reverse of case (b), and Fig. 470 shows that the image is real, inverted, larger than the object, and beyond the center of curvature.

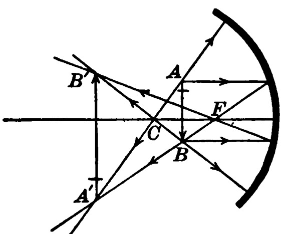


FIG. 470

(e) *When the Object is at the Principal Focus.* — This is the reverse of case (a). The rays are sent off in parallel lines; hence the image is at an infinite distance away; that is, there is none.

(f) *When the Object is between the Principal Focus and the Mirror.* — In this case, as shown in Fig. 471, the reflected rays are divergent, and there can be no real image. By prolonging these rays behind the mirror, however, the image is seen to be virtual, upright, and larger than the object.

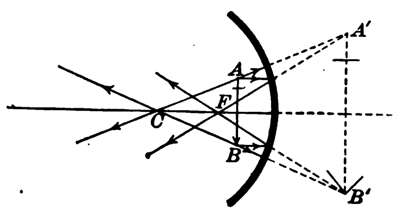


FIG. 471

Rev.

504. Relative Size of Object and Image. — To get an expression for the relation between the size of the object and that of its image, it is only necessary to study the geometrical construction of such a figure as that in case (*b*). From similar triangles in Fig. 468 it is seen that $AB : A'B' = CD : CD'$. That is, *the length of the object is to the length of the image as the distance of the object from C is to the distance of the image from C.* Experiment shows that

$$\frac{1}{F} = \frac{1}{D_o} + \frac{1}{D_i}, \qquad (62)$$

in which F is the principal focal length, or practically half the radius of curvature, D_o the distance of the object from the mirror, and D_i the distance of its image. From this formula any one of these three distances can be found if the other two are known.

505. The Convex Mirror. — If the outside of a sphere is made the reflecting surface, the mirror is convex. The focus and image are determined as in the case of the concave mirror, except that the reflected rays must be prolonged behind the mirror before they meet, and hence the image is a virtual one. It is also upright and smaller than the object, as a construction like Fig. 472 will show.

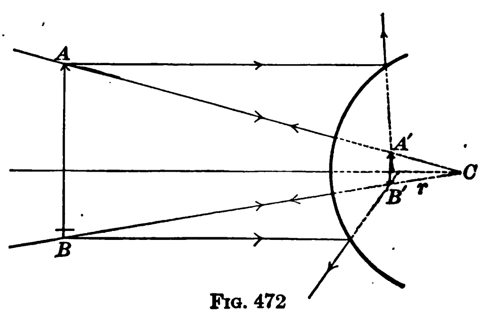


Fig. 472

Demonstrations. — Using two mirrors, one concave and the other convex, verify the statements in §§ 503–505. Observe that the *real*

image can be caught on a screen, while the *virtual* cannot, though both alike can be seen with the mirror. A piece of ground glass forms an excellent screen.

Hang a concave mirror on the wall so that its center is at the height of the eye. Let two students of the same height stand in front of the mirror 10 or 15 feet away. While one watches the image of the second, let the second walk slowly toward the mirror. By careful observation, student No. 1 can see the inverted image of the face of student No. 2 advance from the mirror and finally rest upon the shoulder of No. 2 when he is at the center of curvature.

If the concave mirror used in Fig. 466 is turned over, its opposite side can be used for a convex mirror. Figure 473 shows how a group of parallel rays are reflected as a diverging pencil. The focus of these rays can be found by projecting the outer rays behind the mirror. From this position the focal length can be found; it will be practically half the radius of curvature.

FIG. 473

506. Spherical Aberration. — If the angular opening of the concave mirror is large, the principal focus for parallel rays near the axis will be farther from the mirror than that for those near its edge (Fig. 474). For this reason the outside of an image sometimes looks blurred. To prevent this *spherical aberration* the aperture should not exceed 10° or 12°. Spherical aberration can be avoided by the use of parabolic mirrors, such as are used in headlights for locomotives and electric cars. The rays of light coming from a lamp in the focus of such a mirror are sent off as parallel rays.

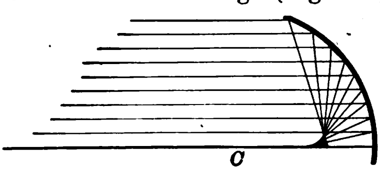


FIG. 474

Questions

1. Define the angle of reflection.

2. Refer to Fig. 460 and show how you determine the positions of C' and C''.

3. What relation is there between the first and second of the multiple images in a plate-glass mirror and the thickness of the glass?

4. What difference is there between the image that a person sees of himself in a mirror and the appearance he presents to other people?

5. Prove that the shortest plane mirror in which you can see your entire figure when you are standing erect and the mirror is vertical, is one half your height.

6. Where must the light be placed if the concave mirror of an automobile lamp is to throw a parallel beam of light?

7. What effect will it have upon the shape of the beam to bring the lamp nearer the mirror?

8. Describe the changes that take place in the image of an object when it is brought from an infinite distance to the surface of a concave mirror. Consider location, position, size, and character of the image.

9. What are the distinguishing characteristics of the image seen in a convex mirror?

Problems

1. What is the angle of incidence when the angle between the incident and reflected rays is 38°?

2. The sun is 40° above the horizon. What is the angle of incidence when its light shines upon the surface of a pond?

3. A boy stands 6 feet in front of a vertical plane mirror. What is his distance from his image?

4. The point of a pencil is placed on the front surface of a piece of plate glass and the image is one inch from the point. How thick is the glass?

5. A lamp is placed one foot in front of a vertical plate of glass three quarters of an inch thick. What is the distance between the two images?

6. A concave mirror has a radius of curvature of 4 ft. At what distance from the mirror is the image of the sun formed by it?

7. A rod 18 in. long is placed erect 6 ft. in front of this mirror. How far in front of the mirror will its image be? What will be its length? Solve by construction. Solve also by Formula 62.

8. A man standing 8 ft. in front of two mirrors, one concave and the other convex, observes his image in each. What is the difference between them if each has a radius of 4 ft.?

III. REFRACTION OF LIGHT

507. Refraction. — If a heavy pencil line is drawn on a sheet of paper and a piece of plate glass is laid over it, the line seen through the glass will be a continuation of the part that the glass does not cover, as in (*a*), Fig. 475, provided the eye is directly in front of the line. If, however, it is on one side, the line will appear to be a broken line as in either (*b*) or (*c*). The reason for this appearance is that the light coming from the line to the eye has its direction changed at the surface of the glass. This bending of the ray, called *refraction*, takes place whenever light passes obliquely from one medium into another of different optical density.

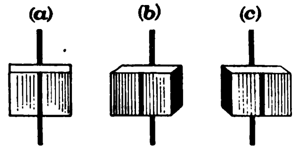


FIG. 475

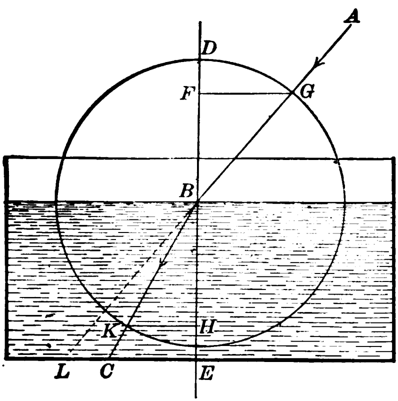


FIG. 476

508. Angles of Incidence and Refraction. — Water is optically denser than air. Let the incident ray *AB* (Fig. 476) strike the surface of water at *B*. Part of the light will be reflected,

part absorbed, and part will pass through the water. This last part, the refracted ray, will take the direction BC. Draw the normal DE to the surface at B; then the angle ABD is called the *angle of incidence*, and the angle EBK the *angle of refraction*. The angle CBL, which is the difference between the angles of incidence and refraction, is the *angle of deviation*.

509. Cause of Refraction. — When a beam of light moving in one medium strikes the surface of another, the part that enters the new medium will have its velocity changed. If the new medium is optically denser than the old, the velocity will decrease, while if it is optically rarer, the velocity will increase.

Suppose the beam has the wave front LF (Fig. 477) and is moving in the direction CD. When the ray EF passes the surface xy, its velocity in the new medium is less, and by the time the ray AL has reached B, the ray EF will have gone only the distance FG from F, the ray CD will have reached H, the new wave front will be BG, and as the direction of light is always perpendicular to the wave front, the new direction will be DH.

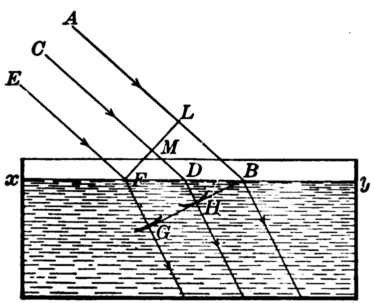


Fig. 477

510. Index of Refraction. — If Fig. 477 represents light passing from air into water, FG is the distance the light travels in water while it travels the distance LB in air. Hence $LB : FG = V : v$, where V and v are the velocities in air

and water respectively. Since V and v are constant velocities the ratio $\frac{V}{v}$ must also be a constant and this is called the *index of refraction*.

The index of refraction is a constant for all angles of incidence and is the same as the ratio of the velocities of light in the two media.

511. The Laws of Refraction.

I. *When a ray of light passes obliquely from an optically rarer to an optically denser medium, it is bent toward the perpendicular to the surface at that point. When it passes from an optically denser to an optically rarer medium, it is bent from the perpendicular.*

II. *The incident and refracted rays, and the normal to the refracting surface, are in the same plane.*

III. *Whatever the incident angle, the index of refraction for any two media is a constant quantity.*

512. Indices of Refraction. — Since the ether is the real medium for the transmission of light, and since the velocity is greater in ether alone (*i.e.*, in a vacuum) than in ether associated with any kind of matter, there are two kinds of indices of refraction: one is the *absolute index*, shown when the ray passes from a *vacuum* into a substance; the other is the *relative index*, shown when the ray passes from one *substance* into another.

The relative index of two substances is found by taking the inverse ratio of their absolute indices. Approximately, the index of refraction for light passing from air to water is taken as $\frac{4}{3}$; to crown glass, $\frac{3}{2}$; to flint glass, $\frac{8}{5}$; and to diamond, $\frac{5}{2}$.

TABLE OF ABSOLUTE INDICES OF REFRACTION (YELLOW LIGHT)

Vacuum	1.00000	Carbon Bisulphide . .	1.624
Air	1.00029	Crown Glass	1.516
Water	1.334	Flint Glass	1.651
Alcohol	1.360	Diamond . . .	2.47 to 2.75

513. Total Reflection; Critical Angle. — Demonstration. — Fix on the optical disk a semicircular piece of plate glass, as in Fig. 478. Rotate the shield and allow a single narrow band of light to strike on the cylindrical surface at various angles to the horizontal. At some angles the beam on reaching the plane side of the glass will be reflected back into the glass and pass out at the upper surface. At other angles part of the beam will pass through the glass, undergoing refraction as it leaves the plane surface. At a certain angle of incidence the refracted beam will just graze the plane surface of the glass.

FIG. 478

This angle of incidence, where total reflection begins, is called the *critical angle*, and varies with the media. The critical angle for light passing from water into air is about 48.5°; from crown glass into air, 42°; and from diamond into air, 24°.

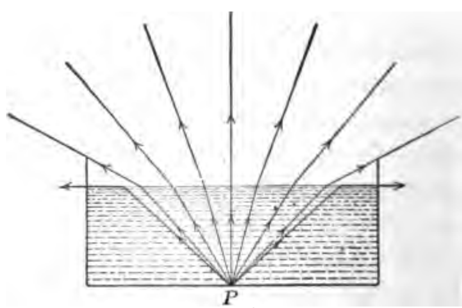


FIG. 479

514. Effect of Total Reflection. — If a luminous point is placed at the bottom of a vessel of water (Fig. 479), it will send rays of light in all directions. All the rays that are within a cone, having its apex at the luminous point and

its base in the surface of the water, including an angle of 97°, will pass out into the air. All rays outside of this cone will be reflected from the surface back into the water. This means that the entire space above the water would be seen by an eye looking upward from beneath the surface, within a circle limited by a cone of rays, the angle between any two rays on opposite sides of the cone being 97°. Beyond that circle, the surface of the water acting as a total reflector would reflect the bottom and things lying upon it.

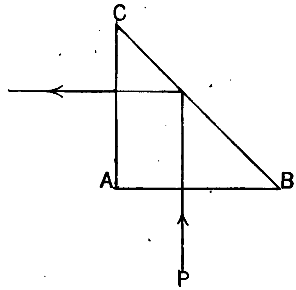


Fig. 480

515. Total Reflecting Prism. — Let ABC, (Fig. 480), represent a right-angled prism the cross section of which is an isosceles triangle. A ray of light from P, perpendicular to AB, will pass through it without change of direction, will strike the face BC at an angle of 45° and, since this is greater than the critical angle, will be totally reflected and pass out normal to the surface AC. A prism of this shape, with polished faces, is one of the most perfect reflectors known. For this reason it is used in many optical instruments.

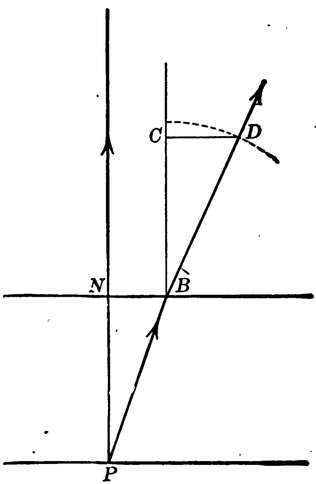


Fig. 481

The direction of any particular ray can be traced from the

water to the air as in Fig. 481. Let *PB* be the ray, the path of which is to be determined. With *B* as a center and *BP* as radius, describe an arc to the right of the normal *BC*. Measure *NB* and lay off four thirds of this distance as *CD* so that *D* shall be on the arc. Then *BD* will be the direction taken by the ray *PB*.

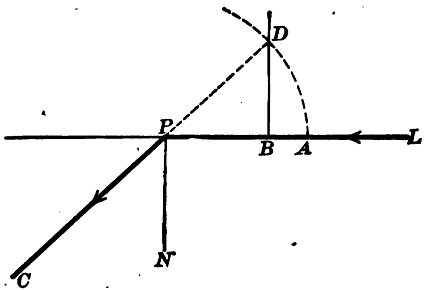


Fig. 482

To determine the critical angle, take the ray *LP* passing along the surface of the water (Fig. 482), and let it be required to find the direction it will take in the water. With *P* as a center and any distance *PA* as radius, describe an arc above *LP*. Lay off *PB* equal to three fourths of *PA* and from *B* erect a perpendicular *BD*. From *P* draw the line *PC* as a continuation of the direction *DP* and the angle *CPN* is the critical angle.[1]

Demonstrations. — Hold a glass of water high, and look through the side of the glass at the surface of the water. Notice that you cannot look through the surface. Put a spoon into the glass, and notice that the part in the water is reflected from the surface.

Fill a beaker two thirds full of water. Into this thrust a test tube with a long, narrow slip of paper in it. Notice that there is a position at which total reflection takes place and the paper cannot be seen through the water. Pour a little water into the test tube, and notice that the paper can be seen wherever the tube has water in it.

516. Effects of Refraction. Whenever a straight stick is placed in water at an angle, as *AB* (Fig. 483), it appears

[1] See Appendix, for proof.

bent at the surface of the water *D*, the part *BD* below the surface seeming to rise, the end *B* taking the position *C*. This effect is due to the refraction of the ray *BF* at *F*, where it takes the direction *FE*, and to the fact that the apparent position of a body is in the direction of the ray that enters the eye.

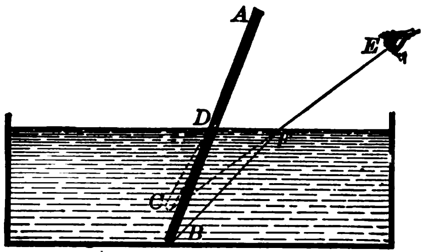


FIG. 483

For the same reason a pond into which one looks seems to be shallower than it really is.

Refraction takes place in gases also, when rays pass from one medium into another of different density. This gives rise to two effects at sunrise and sunset.

First. — The sun is seen when it is really below the horizon. If the line *AB* (Fig. 484) represents the horizon at the point *A*, the sun, though below it, at the point *S*, appears to be at the point *S'*: for the rays from *S*, on striking the atmosphere of the earth and constantly passing into denser layers, are bent downward, and as the ray that enters the eye is from the direction *S'A*, this makes the sun appear to be at *S'*.

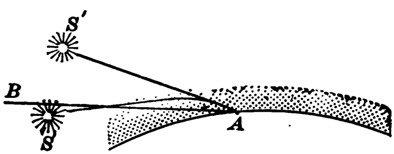


FIG. 484

Second.—Another effect is that upon the apparent shape of the sun. The rays that are nearest the horizon are bent the most, so that the lower side appears higher than it really is, with reference to the upper side. This causes an apparent flattening of the sun near the horizon, especially on the lower side.

517. Refraction through Plates with Parallel Sides. — When light passes through the side of a transparent plate with parallel sides, as at E (Fig. 485), it is bent toward the normal at E, taking the direction EH, as determined by the relative index of refraction, $\frac{V}{v}$. When the light reaches H, the part passing through is bent away from the normal in the direction HK, as determined by the relative index of refraction, which is the reciprocal of the first index. Hence the direction of HK, the emerging ray, is parallel to LE.

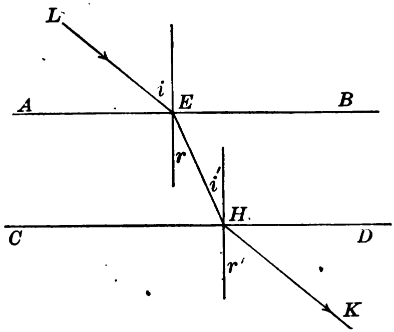


FIG. 485

Demonstration. — This can be shown by using a plate glass with parallel sides in the optical disk. Whatever the angle of the incident beam, it will be seen that the emergent beam is parallel to it.

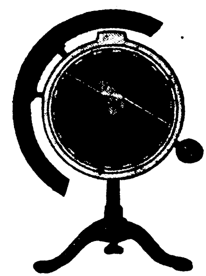


FIG. 486

518. Prisms. — If the surfaces of the transparent medium are not parallel, the emerging ray will not be parallel to the incident ray. When the cross section of the medium is a triangle, the medium is a prism. The path of a ray passing through a prism is shown in Fig. 487. When the ray from

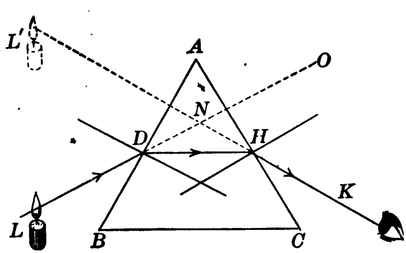


FIG. 487

L strikes the prism at *D*, it is bent toward the normal and passes through the prism in the direction *DH*. When it passes out of the prism at *H* it is bent from the normal in the direction *HK*. *A ray of light passing through a prism is always bent toward the base.* If the eye is placed at *K*, the source of light will appear to be at *L′*. The position of any object seen through a prism is apparently moved toward the *refracting angle*, which is the angle formed by the intersection of the two faces under consideration.

If *L* is raised, the refracted ray *DH* is bent nearer the base and the angle which it makes with the normal to the side *AC* is increased. When it reaches the value 42° the critical angle of the glass is reached and the ray is totally reflected within the glass and emerges from the prism through the side *BC*.

The *angle of deviation* is the angle which the incident and emergent rays form with each other. In Fig. 487 it is the angle *KNO*. This angle varies with the refracting angle of the prism, the index of refraction of the medium, and the angle of incidence. There is for every prism a minimum angle of deviation, and this is obtained when the angles of incidence and emergence are equal.

519. Lenses. — A lens consists of a transparent body bounded by two surfaces, one or both of which are curved. The curved surfaces are usually spherical. There are six forms of lenses in common use, which may be classified in two groups of three each:

1. Double convex 2. Plano-convex 3. Converging meniscus	Converging lenses. Thicker in the middle than at the edge.
4. Double concave 5. Plano-concave 6. Diverging meniscus	Diverging lenses. Thinner in the middle than at the edge.

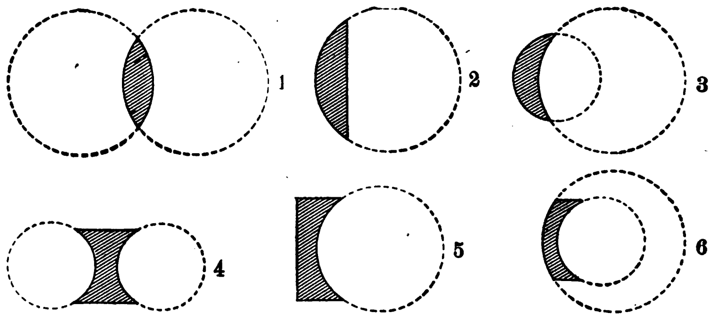


FIG. 488

These lenses may be considered as being formed as follows:

1. Intersection of two spheres.
2. Intersection of plane and sphere.
3. Intersection of small sphere by large sphere.
4. Intersection of cylinder by two spheres.
5. Intersection of cylinder by plane and sphere.
6. Intersection of cylinder by a small and a large sphere.

520. Center of Curvature; Principal Axis; Optical Center. — The centers of the spheres whose surfaces bound a lens are its *centers of curvature*, as C and C' (Fig. 489). The straight line passing through these centers is the *principal axis* of the lens. In plano lenses the principal axis is a line passing through the center of curvature of the curved surface, and normal to the plane surface. The *optical center* of a lens is that point through which a ray of light passes with practically no change in its direction. In a double convex lens having the same curvature for both sides, it is the center of the figure. In plano lenses it is at the intersection of the curved surface and the principal axis.

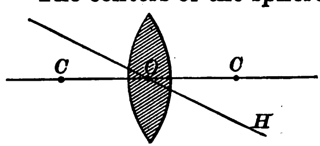


FIG. 489

Any ray which passes through the optical center, but does not pass through the center of curvature, is a *secondary axis*, as *HO* in Fig. 489.

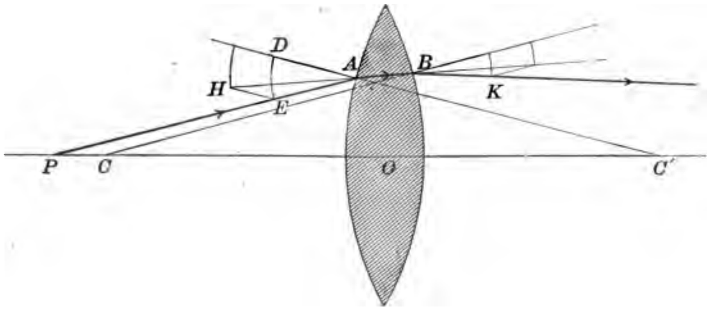


FIG. 490

521. The Path of a Ray through a Lens. — Suppose the ray to come from the point *P* on the principal axis and to strike a crown-glass lens at the point *A* (Fig. 490). The direction *AB* through the lens may be found as follows:

Describe from *A* as a center two arcs of circles with radii that are to each other as 3 : 2 ($\frac{3}{2}$ being the index of refraction of the lens). From *E*, the intersection of the ray with the inner arc *DE*, draw a line parallel to the normal *DA*, and from *H*, where the parallel intersects the outer arc, draw *HA* and prolong it to *B*.

In a similar way we can determine the direction, *BK*, that the ray will take on emerging from the lens.

522. The Foci of Convex Lenses. — The positions of the luminous point for which we may determine foci in convex lenses are similar to those considered for concave mirrors. To determine the focus of any point, two rays only are needed. The principal axis or a secondary axis is taken for one of these rays.

(*a*) *When the Luminous Point is at an Infinite Distance.* — In this case the incident rays are parallel, and if we take the index of refraction as $\frac{3}{2}$, the focus is very near the center of curvature for a double convex lens, and at twice that distance for a plano-convex lens. This is the *principal focus*, and its distance from the lens is the *focal length* of the lens.

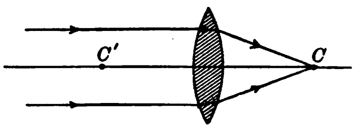


FIG. 491

(*b*) *When the Luminous Point is at a Finite Distance More than Twice the Focal Length.* — If the path of the ray PA (Fig. 492) is constructed, it will be found to intersect the principal axis at P', between C' and twice the focal length.

(*c*) *When the Luminous Point is at Twice the Focal Length.* — A construction will show that the focus is also at twice the focal length on the other side of the lens.

(*d*) *When the Luminous Point is at Less than Twice and More than Once the Focal Length.* — This is the converse of (*b*), as is shown in Fig. 492, since if the luminous point is P', its focus will be P.

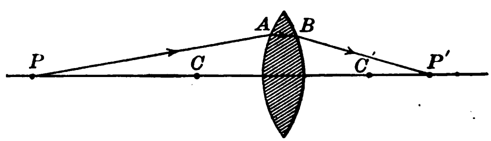


FIG. 492

(*e*) *When the Luminous Point is at the Principal Focus.* — This is the converse of (*a*), and the emergent rays will be parallel to the principal axis.

(*f*) *When the Luminous Point is between the Principal Focus and the Lens.* — In this case the rays will emerge as divergent rays, and the focus will be virtual, on the same side of the lens as the luminous point, and farther away from the lens.

Converging lenses render parallel rays converging, increase the convergence of converging rays, and decrease the divergence of diverging rays, or render them parallel or converging.

FIG. 493

Demonstration. — Figure 493 shows how the focus of parallel rays can be found by the use of the optical disk.

523. The Foci of Concave Lenses, — (*a*) *When the Incident Rays are Parallel.* — In this case the rays emerge as divergent rays (Fig. 494), and the focus is virtual. In the double concave lens of crown glass the focus is practically at the center of curvature; in the plano-concave of crown glass, at twice that distance from the lens.

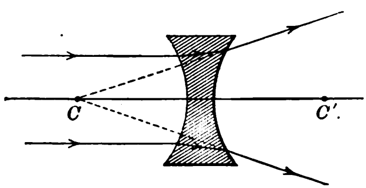


FIG. 494

(*b*) *When the Incident Rays are Diverging.*—In this case a construction will show that the emergent rays are more diverging, and that the virtual focus is nearer the lens than in case (*a*).

(*c*) *When the Incident Rays are Converging.* — In this case the rays are rendered less converging, parallel, or diverging, and the position and kind of focus, if any, will depend upon the amount of convergence in the incident rays.

Diverging lenses render parallel rays diverging, increase the divergence of diverging rays, and decrease the convergence of converging rays, or render them parallel or diverging.

FIG. 495

Demonstration. — Figure 495 represents the paths of parallel rays on passing through a double concave lens. The focal length of the lens can be found by prolonging the diverging rays back until they meet.

524. The Formation of Images by Lenses. — **Demonstration.** — Take a convex lens, a candle, and a screen into a dark room. Arrange them in line as in Fig. 496, and by varying the relative distances study the images of the candle formed on the screen by the lens. Since the image of an object is made up of the foci of all its points, verify the positions given for these foci in § 522.

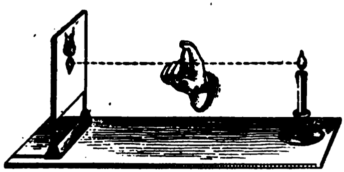


FIG. 496

525. Formula for Convex Lenses. — The relative positions of an object and its image formed by a convex lens can be determined if the principal focal length is known, and *vice versa*. The formula, like that for concave mirrors, is,

$$\frac{1}{F} = \frac{1}{D_o} + \frac{1}{D_i}, \tag{62}$$

in which F is the focal length, D_o the distance of the point P from the lens, and D_i the distance of its image from the lens. If we let S_o represent the length or diameter of the object, and S_i that of the image, then a simple geometrical construction shows that $S_o : S_i = D_o : D_i$.

526. Geometrical Construction of Images. — The image which any lens will give of an object can be constructed with great accuracy. To do this two rays only are needed, from each end of the object. These rays are the secondary axis, which will pass through the optical center of the lens, and a ray parallel to the principal axis, which, after passing

through the lens, will pass through its principal focus. The image of the arrow AB (Fig. 497) formed by the lens D will be $A'B'$. The parallel ray AG, passing through the lens in the direction GH, will then pass through C', and its intersec-

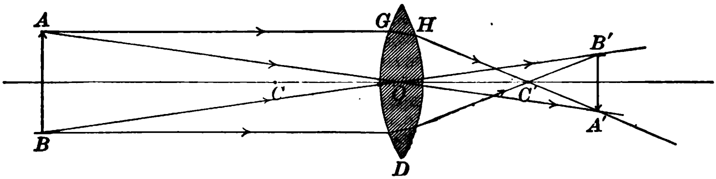


FIG. 497

tion with the ray AO continued will locate the image of A at the point A'. The image of B can be found in the same way. From a consideration of the triangles ABO and $A'B'O$ it is seen that $\dfrac{\text{Size of image}}{\text{Size of object}} = \dfrac{\text{Distance of image}}{\text{Distance of object}}$.

527. Spherical Aberration. — In order that the results mentioned in the preceding discussion on lenses may be obtained experimentally the lenses must be thin and the aperture small. If a thick convex spherical lens is used, the rays that pass through it near the edge do not focus at the same point as those that pass through near the middle of the lens.

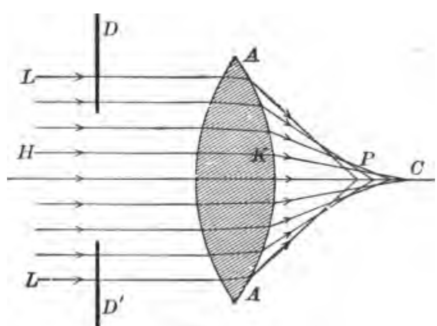


FIG. 498

This can be shown by construction as in Fig. 498. The rays LA come to a focus at P, and only those rays quite near

the center focus at C. The effect of this is to make the outside of the image indistinct when the center is distinct, and *vice versa*. This defect may be remedied by using a diaphragm with a hole in it, in front of the lens, as DD'. This makes the image more distinct, but as it cuts off the light from the outside, the image is not so bright.

Questions

1. Suppose P to be a luminous point at the bottom of a dish filled with water to the line AB. Construct the paths of the rays PC, PD, and so on, making angles of 10°, 20°, 30°, and so on, with the normal PN. Trace as many of these paths as will strike on the surface AB. Let AB be 10 in. long and the water 6 in. deep.

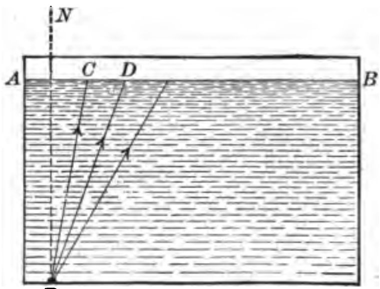


FIG. 499

2. Suppose you place a block of crown glass 2 in. thick upon a point P on the table. Construct the paths of rays passing from P at the same angles as in problem 1.

3. Explain why the amount of light reflected from a diamond is greater than that from a piece of glass cut in the same shape.

4. Why does an oar placed in the water appear bent?

5. Why is there a difference between the apparent diameters of the full moon when it is rising and when it is well up in the sky?

6. Why does a vertical straight line, when looked at in a slanting direction through a piece of ordinary window glass, appear to be full of short bends, while if it is looked at through a piece of plate glass it appears straight?

7. Prove that a ray of light passing through a prism is bent toward the base.

8. Construct the paths of rays emerging from a double convex lens when the luminous point is between the principal focus and the lens.

9. Construct the paths of rays emerging from a double concave lens when the incident rays are diverging.

10. The radius of curvature of each surface of a double convex lens is 3 ft. Construct the image it forms of an arrow 4 ft. from the lens.

Problems

1. The distance of the object is 18 in. from a converging lens and the distance of the image is 6 in. What is the focal length of the lens?

2. Suppose that using the same lens as in problem 1, the image is found to be at the same distance from the lens as the object. What is the distance?

3. A reading glass has a focal length of 3 in. How far from the glass will it form the image of a lamp 4 ft. away?

4. What is the height of the image in problem 3, if the lamp is 3 in. high?

5. When the image of an object 24 in. from a convex lens is thrown upon a screen at a distance of 6 in. from it, what is the focal length of the lens? What are the relative lengths of image and object?

6. Find the focus of a point 30 cm. from a convex lens when the focal length is 20 cm.

IV. DISPERSION AND POLARIZATION

528. Color is a property of light that depends on its wave length. Red light, for instance, consists of ether vibrations with a wave length of about 0.0007 mm., while vibrations with a wave length of 0.0004 mm. produce the sensation of violet light.

529. The Dispersion of Light. — Demonstration. — Take a prism into a dark room and hold it in front of a horizontal slit in a shutter. When a beam of sunlight passes through the prism, it is not only refracted, but separated into a band of colors on the opposite wall.

This *dispersion* is due to the fact that the index of refraction in a glass prism varies with the wave length of the light.

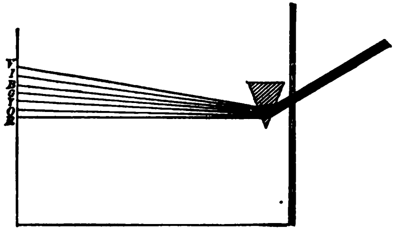


Fig. 500

The spectrum formed is called the *solar spectrum*, and consists of a series of colors passing imperceptibly from violet, which is refracted the most, through indigo, blue, green, yellow, and orange, to red, which is refracted the least.

Demonstration. — Paste two narrow bands of paper, one violet and one red, upon a black card, and look at them through a prism. It will be seen that the red rays are refracted less than the violet.

530. Recomposition of White Light. — Since the spectrum is formed by the unequal dispersion of white light, it is possible to reproduce white light by bringing all the spectrum colors to one place. This can be done by using a second prism reversed, a concave mirror, or a convex lens.

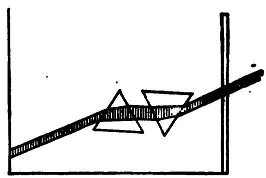


Fig. 501

Demonstration. — Set up a prism in a dark room and let the sunlight strike it through a slit in the shutter. Let the spectrum fall upon a second prism which is reversed. The spectrum colors being brought together will produce a brilliant white line.

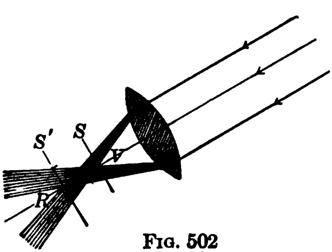


Fig. 502

531. Chromatic Aberration. — **Demonstration.** — Place a large double convex lens perpendicular to the sun's rays (Fig. 502). If a screen is placed at S, a picture of

the sun will be formed having an outer fringe of *red*, but if the screen is placed in the position S' the fringe will be *violet*.

This effect, which is quite common in single lenses, is called *chromatic aberration*, and is due to the unequal refraction of the different colors.

532. The Achromatic Lens. — Achromatism, or the formation of images without colored fringes, is secured by combining a plano-concave lens of flint glass with a double convex lens of crown glass. These are of such curvatures that the dispersion of one is neutralized by that of the other, while the refraction is retained. The refraction of the combination is less, however, than that of the double convex lens alone.

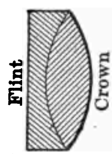


FIG. 503

533. The Rainbow. — One of the most familiar and striking results of refraction and dispersion in nature is seen in the rainbow. Whenever rain is falling and the sun is shining upon it, from a point not too high in the heavens, an observer standing with his back to the sun will see one and sometimes two of these brilliant bows.

The inner or *primary bow* is composed of the spectrum colors in their order, the red being on the outside and the violet on the inside. The outer or *secondary bow* is composed of the same colors, but in inverse order.

534. The Primary Bow. — When a beam of sunlight L strikes upon a raindrop at A (Fig. 504), the light that passes into the drop is refracted at A and dispersion begins at the same place, so that when the light strikes the back of the drop it is as a spectrum, with the red ray above on account of its refraction being the least. At RV part of the light passes out of the drop, but part is reflected. Since the angle

of incidence ARO is greater than the angle AVO, the angle of reflection ORR' must be greater than the angle OVV', and for this reason the rays will cross at B and emerge (in part) from the drop at R' and V' in the directions $R'R''$ and $V'V''$. The other spectrum colors will be refracted in regular order between R'' and V''.

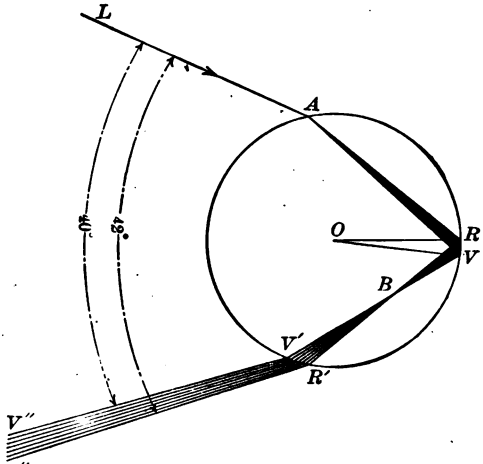


FIG. 504

The angle of incidence at which these results are obtained is such that the red ray leaves the drop at an angle of 42° to the direction of the entering ray, and the violet ray at an angle of nearly 40°. Hence the red ray is seen at an angle of 42° and the violet at an angle of about 40° to a line drawn from the observer

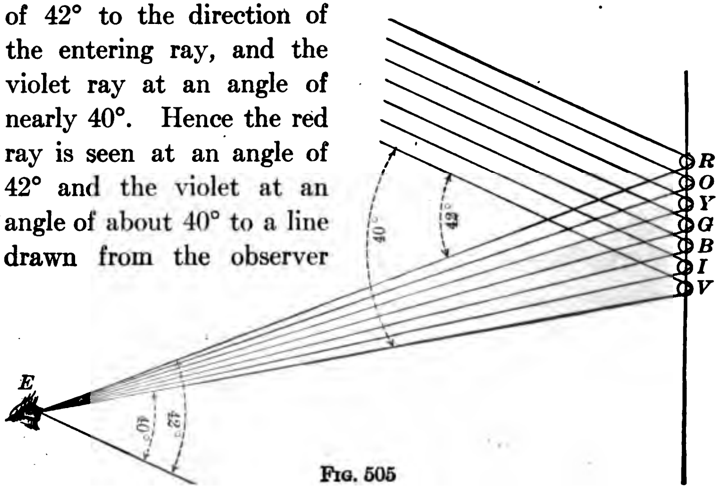


FIG. 505

directly away from the sun. Since the angle for the red ray is greater than for the violet, it is evident that if the eye is placed at E (Fig. 505) the different colors will be seen reflected from different drops, and that the drop giving the red ray will be higher than the others. This explains why the red is on the outside of the primary bow.

Demonstration. — By using a thick cylinder of glass with the optical disk, the path of a ray similar to that which forms the primary bow in a raindrop can be traced as represented in Fig. 506.

FIG. 506

535. The Secondary Bow. — The sun's rays striking on the lower side of the raindrop at A (Fig. 507) will be (in part) refracted and dispersed to VR, and then after two reflections

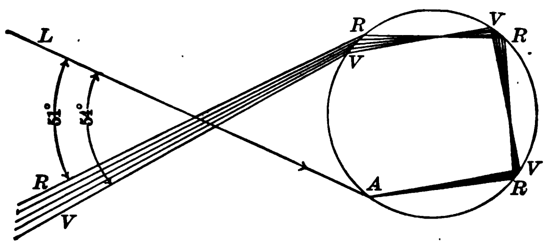


FIG. 507

part of them will emerge from the drop, the red at an angle of 51° and the violet at an angle of 54° to the direction of the entering ray. This means that the eye will receive the violet ray from a higher elevation than the red ray, and hence that the violet will be on the outside of the secondary bow.

536. Why the Rainbow is Circular. — Since the raindrop is a sphere, the red rays of the primary bow are sent off in

the form of a cone having the drop at its vertex and making an angle of 42° with the axis of the cone. The red ray, therefore, can be seen, from different drops, in any direction that makes an angle of 42° with the axis of the bow, that is, with the line that passes through the sun and the eye of the observer; and hence its form will be circular. In Fig. 508 the sun is supposed to be at the horizon.

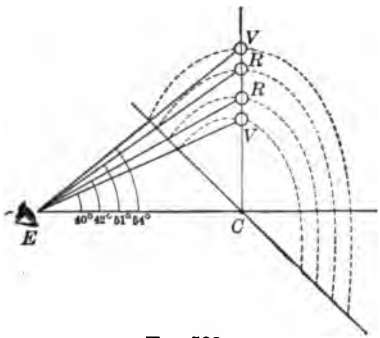


Fig. 508

537. The Color of Opaque Bodies under white light is determined by their relative powers of absorbing and reflecting vibrations of certain wave lengths. A body that absorbs all the colors except red, reflects that color and is red.

Demonstrations. — Paste a strip of white paper upon a black card and, holding it in the sunlight, examine it by looking through a prism.


Fig. 509

The edges of the paper will give the spectrum colors. Examine in the same way strips of red and blue paper, and the spectrum in each case will give only the color that the paper reflects.

Paste a strip of white paper, 10 in. long and $\frac{1}{4}$ in. wide, on a black card. Paste, at right angles to this, pieces $\frac{1}{8}$ in. wide and 2 in. long. Place a prism as in Fig. 509, and examine the strips. The

spectra of the narrow strips into which we may suppose the long strip to be divided will overlap and give white light except at the ends, one end being red and the other violet. The spectrum of each narrow line will be a complete spectrum.

If the color that a body reflects is red, it will not appear red unless the light that shines upon it has red in it.

Demonstration. — Take slips of differently colored paper into a dark room and examine them under the light from a photographer's lamp giving a ruby red light, or under the yellow light from a candle upon which some salt has been sprinkled.

This demonstration shows the importance of selecting colors under the same light as that in which they are to be used. A color that is exactly suitable by daylight may have an entirely different appearance by gaslight.

An artificial light is better adapted for all purposes when the quality of its light approaches that of sunlight. Most artificial lights have a greater proportion of yellow in them than daylight has. The colors of the decorations used in a room should be determined in a great measure by the color of its illumination.

538. The Color of Transparent Bodies, viewed by transmitted light, depends upon the color that they transmit. If a body transmits all colors equally, it is colorless. If it transmits one color only, — yellow, for example, — then it will have that color; but if it transmits several, its color will be that which results from combining the transmitted colors in the relative amounts in which they are transmitted.

539. Newton's Disk. — Sir Isaac Newton used a method of combining colors that depends upon the principle of *persistence of vision* in the eye. If a cardboard disk is painted red on one sector and yellow on the other, as in *A* (Fig. 510),

and if it is then rapidly rotated on an axis passing through the middle of the disk, the color will appear to the eye to be orange. This is purely a physiological result, the red sensation following the yellow sensation so quickly that the result is a combination of the two. If violet and red are used instead of yellow and red, the result will be purple. Combinations of any colors, in any proportions, can be made by having a disk of each color slit radially, as *B* in Fig. 510, so that they can be slipped over one another while on the axis.

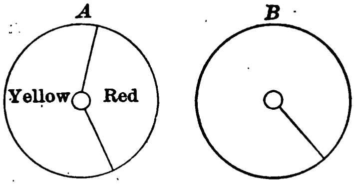


FIG. 510

540. Complementary Colors. — If blue and orange are used in the right proportions in Newton's disk, the resulting effect will be practically white. Two colors which, added together, produce white, are called *complementary colors.*

A chart like that shown in Fig. 511 is convenient for showing complementary colors. It is so arranged that the combination of any two colors opposite will produce white, and the combination of any two spectrum colors will produce the color between them; *e.g.*, red and yellow will produce orange. Yellow and blue in varying proportions will produce varying shades of green; and red and blue in varying proportions will produce varying shades of purple and violet.

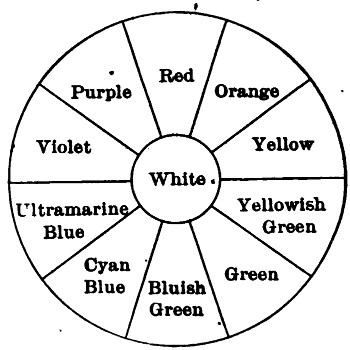


FIG. 511

The three-color process is a method of making colored pictures of almost any tint or shade of color by using only three colored inks in printing. Photographic negatives of a colored picture are made through screens of red, blue, and yellow. Copper plates are engraved from these and each is inked with its color. By printing these, one over the other, in exact register, very pleasing results are obtained. (The frontispiece of this book is printed by this process.)

541. Camouflage. — The protective coloring of quail, zebras, and many other animals makes them difficult to distinguish from their native landscapes. In the World War a similar principle was extensively applied in "camouflage"— the painting or screening of cannon, ships, and other things to conceal them from observation by the enemy. In the case of merchant ships, however, it was found more feasible to use the deceptive "dazzle" system of camouflage. (See frontispiece.)

542. The Spectroscope is an instrument for the production and study of the spectra from different sources. It has three essential parts, shown in diagram in Fig. 512.

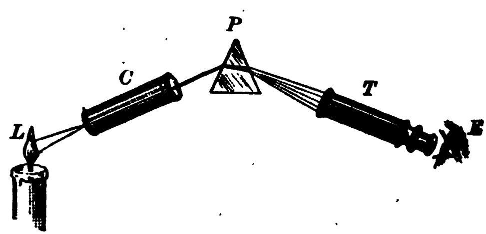


Fig. 512

The *collimator* C is provided with a slit at the end nearest the light L, and a lens so arranged that the light will pass from the collimator to the prism in parallel lines. The prism P is fixed in such a position that the refracted beam passes through it and emerges in the direction of PT. The telescope T is movable, and can be focused on any ray that emerges from the prism. A general view of one form of the instrument is shown in Fig. 513.

543. Spectrum Analysis. — The kind of spectrum that is given by any source of light depends upon the physical condition of the source. There are three kinds of spectra: the *continuous spectrum*, the *bright line spectrum*, and the *absorption* or *dark line spectrum*.


FIG. 513. — Spectroscope

544. First Law of the Spectrum. — **Demonstration.** — Examine the flame of a candle by the spectroscope, and it will be seen to be continuous from the red end to the violet, passing through all the intermediate colors by imperceptible gradations.

LAW I. *When the source of light is an incandescent solid, liquid, or dense gas, the spectrum is continuous.*

The continuous spectrum in the above demonstration is the spectrum of incandescent solid particles of carbon from the candle. The same kind of spectrum is obtained from a lamp or gaslight.

545. Second Law of the Spectrum. — **Demonstration.** — Dip a platinum wire in a solution of salt and hold it in a nonluminous Bunsen flame; or soak a strip of cloth or asbestos in salt water and wind it around the top of a Bunsen burner. Examine the flame with the spectroscope, and instead of a continuous spectrum, a bright yellow band will be seen in the middle of the place occupied by the yellow of the continuous spectrum.

This yellow band is called the *sodium line*, or *D line*, and on being closely studied is seen to be made up of two narrow bright lines with a dark band between them.

Law II. *Incandescent gases, not under great pressure, give a spectrum made up of bright colored lines on a dark background.*

Each line has a definite position in the spectrum, and is characteristic of the substance which produces it.

546. Third Law of the Spectrum. — **Demonstration.** — Examine sunlight by the spectroscope, and the colored spectrum will be seen to be crossed by a series of dark lines. Moisten a platinum wire with a solution of salt and hold it in a Bunsen flame in front of the slit. One of the dark lines, the *D* line, will be made darker. Shut out the sunlight and examine the sodium flame alone, and the *D* line will show in the same place as a bright yellow line.

We see in this demonstration that the passage of sunlight through sodium vapor — itself capable of giving a bright line — intensifies the dark line in the solar spectrum. The fact that this dark line is in the same place as the bright line does not mean that there is no sodium in the sun, but instead means that the sodium vapor in the sun's atmosphere absorbs the light of the same wave length as that given out by incandescent sodium, and makes this part of the spectrum look dark in comparison with the rest of it. Such spectra are called *absorption spectra.*

Law III. *The vapor of any substance will absorb the light given out by that substance in a state of incandescence.*

Absorption spectra can be shown by holding in front of the slit of a spectroscope a test tube containing a solution of potassium permanganate when the solar spectrum is being observed. It will then be seen that the spectrum is crossed by a number of dark bands. The vapors of barium and strontium will produce similar results.

547. Fraunhofer Lines. — The dark lines described above are called the *Fraunhofer lines,* and on account of their inva-

riable position are used as standards of wave length. A careful comparison of the position of these lines with the bright line spectra of iron, copper, silver, zinc, sodium, and many other elements shows that they have exactly the same wave lengths, and hence it is concluded that these elements exist

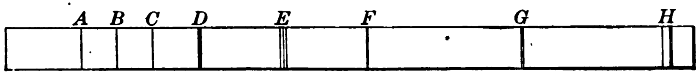


Fig. 514

in the atmosphere of the sun in a state of vapor. The positions of the most prominent of the Fraunhofer lines are shown in Fig. 514, in which the violet end of the spectrum is at the right.

Line	Color	Wave Length in mm.
A	Dark Red	0.0007594
B	Red	0.0006870
C	Orange	0.0006563
D_1	Yellow	0.0005896
D_2	Yellow	0.0005890
E_1	Light Green	0.0005270
F	Blue	0.0004861
G	Dark Blue	0.0004308
H	Violet	0.0003968

The above table gives the wave lengths of some of the dark lines of the spectrum. There are parts of the visible spectrum in the red end that have longer wave lengths than the A line, as well as parts in the violet that have shorter wave lengths than the H line.

548. The Invisible Spectrum. — The visible spectrum is by no means the limit of the dispersion secured by the

prism. Beyond the red are a series of longer waves that can easily be detected as *heat rays,* while beyond the violet are shorter waves that have great chemical activity, and are called the *chemical* or *actinic rays.*

Demonstration. — Cut a piece of photographic printing paper into strips and pin them end to end upon the wall of a dark room so as to form a long strip. By means of a prism throw the solar spectrum upon the middle of the strip, which should extend a third of its length beyond each end of the spectrum. Mark the position of every color and the end of the visible spectrum. After a short exposure notice that the greatest effect on the paper is at the violet end of the spectrum or just beyond it, and that at the red end there is practically no change.

549. Doppler's Principle Applied to Light Waves. — The position of the dark lines of the spectrum is invariable only when the distance between the source of light and the observer is fixed. If this distance is regularly diminishing, the wave length corresponding to a given line diminishes, and if it is increasing, the wave length increases.

If the spectrum of a star is examined, and it is found that the C line, for instance, is located at the right of the position of that line in the solar spectrum, as the lighter line in Fig. 515, the explanation is that the

Fig. 515

star is moving toward us and thus shortening the wave length that produces the line. If the displacement is toward the red end of the spectrum, then the star is receding from us. Since the velocity of the star determines the amount of this displacement, a measurement of this amount can be used as a basis for calculating the velocity of the star's motion.

550. Interference. — We have already seen the results of interference in sound waves. Two waves may meet in such a way as to strengthen each other or to neutralize each other. Similar phenomena occur in light.

Demonstration. — Against a piece of plate glass press the curved side of a plano-convex lens of great focal length. On looking at the upper surface of the lens at an angle, a series of concentric circles will be seen, each one of which will be made up of the colors of the spectrum. If a sheet of red glass is placed between the lens and the light, so that light of that color alone falls upon the lens, the rings will be alternate dark and red bands. Two strips of plate glass separated at one end by a sheet of paper and pinched together at the other will also show interference bands.

The rings shown by the lens are called *Newton's rings.* The colors seen on looking at a thin film of oil on water, a soap bubble, or a crack in a piece of ice, are other examples of interference.

551. Explanation of Newton's Rings. — When light strikes the lens the refracted ray is partly reflected at *A* and its phase is changed.[1] Some other refracted ray will be reflected from *B* without change of phase, and will pass into the air in the same path as the first, *CD*. If the distance *AB* is a quarter wave length, the reflected rays are in the same phase and give light; but if it is a half wave length the reflected rays are in

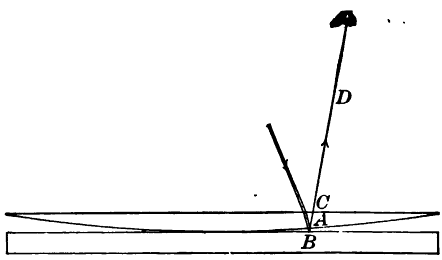


Fig. 516

[1] A change of phase of half a wave length takes place whenever light is reflected back into a dense medium instead of passing into a rarer one.

opposite phases and there is interference or darkness. As the space between the curved surface of the lens and the plane glass increases gradually, there is a distance that corresponds to a quarter wave length for every color of the spectrum.

552. Diffraction.—**Demonstrations.**—Expose a photographic dry plate to daylight. Develop it and fix it. Wash it thoroughly and dry it. With a fine needle or the point of a knife blade draw a series of parallel lines through the film to the glass. Hold this plate close to the eye and look through it at the flame of a candle. There will be seen brilliant spectrum colors extending on either side of the flame.

On one half of the plate used above, draw two sets of parallel lines at right angles to each other, dividing the film into small squares. Look through this at an arc or incandescent light, and fine lines of spectra will be seen to extend at right angles from the light.

A fine silk handkerchief gives a good effect when looked through, especially when the light examined is an arc light. A plate of glass upon which a little lycopodium powder has been sprinkled gives a series of beautiful rainbow effects when a candle or any bright light is seen through it. The cause of these phenomena is that rays of light on passing through a narrow slit spread out into a diverging band, or are *diffracted;* and if the edges of the slit are near each other, interference takes place and gives colored fringes.

The *diffraction grating* consists of from 10,000 to 20,000 parallel lines to the inch, ruled on glass or on speculum metal. If on the former, the light passes through, if on the latter, it is reflected from the polished and ruled surface. Spectra of wide dispersion can be obtained from such gratings, and they are used in place of the prism in spectroscopic work. The spectrum given by the grating is called the *normal spectrum,* since in it the distribution of the different wave lengths is uniform.

553. Polarized Light. — The vibrations of the ether that produce a ray of light are transverse vibrations in every direction. Figure 517 may be taken to represent a cross section of a ray of light, showing vibrations in a few of these directions. If all the vibrations were parallel transversely, as in Fig. 518, then the ray would be a ray of *plane polarized light.* Polarized light affects the eye just like ordinary light, but it presents certain very interesting phenomena, some of which are shown in the following pages.

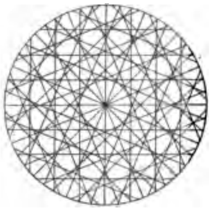


FIG. 517

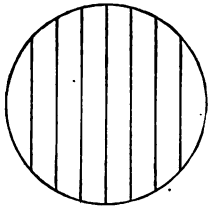


FIG. 518

The crystal tourmaline has the property of permitting vibrations in only one plane to emerge from it; that is, it polarizes light.

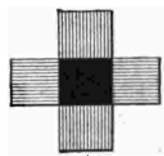


FIG. 519

Demonstrations. — Place two tourmaline crystals one over the other and parallel to each other. The light that passes through one will pass through the other. Now turn one of them until it crosses the other at right angles, as in Fig. 519, and no light at all passes through the crossed portion. The action is as though each let through only those vibrations which are parallel to its length. Now put between the tourmalines a piece of quartz or Iceland spar, and on turning one of the tourmalines, brilliant color effects are observed. The effect of the quartz, then, must be to turn the plane of polarization and to enable a part of the light to pass through the second tourmaline, producing the color effects by partial interference of the polarized rays.

Lay a sheet of black paper upon the table. Over this lay a sheet of glass *G* (Fig. 520). Cut out ten or twelve pieces of thin glass, and holding them as at *A* in the figure, look through them at a piece of mica *M* laid upon the glass sheet. Hold the thin glasses at

various angles and elevations, and determine the position in which the most brilliant effects are produced. The same results are ob-

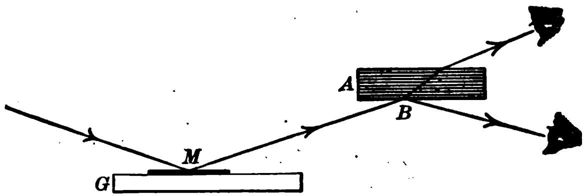


FIG. 520

tained if the eye is placed below the glasses in such a position that the polarized ray is reflected from B.

554. Double Refraction. — If a crystal of Iceland spar AB (Fig. 521) is placed upon a sheet of paper on which there is a black dot, the eye placed above the spar will see two dots, one a short distance from the other and apparently above the surface of the paper. This separation of the light into two rays shows that light passes through the crystal more rapidly in one direction than in the other and is called *double refraction.*

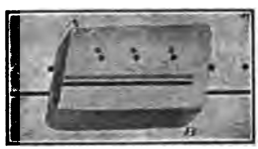


FIG. 521

Two rays from each point reach the eye by different paths: one of them obeys the ordinary laws of refraction, and is called the *ordinary ray;* the other does not obey these laws, and is called the *extraordinary ray.* Another peculiarity of these rays is that they are polarized.

If a crystal of Iceland spar is cut along the diagonal AB and then cemented together again with Canada balsam, it has the property of permitting only the extraordinary ray to emerge. This arrangement is called a *Nicol's prism,* and is much used in the study of polarized light.

555. The Polariscope. — The study of substances by polarized light has become a matter of great importance on account of its use in the detection of adulteration; the substitution of grape sugar for cane sugar, for example. A simple polariscope (Fig. 522) serves to demonstrate many of the phenomena of polarized light nearly as well as more elaborate apparatus.

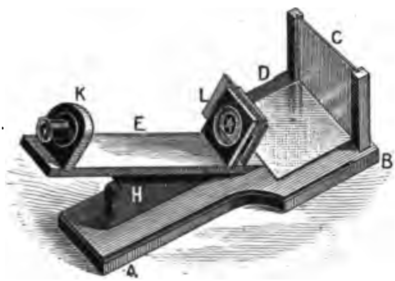


Fig. 522. — Polariscope

The base *AB* supports a vertical ground-glass plate *C*. A piece of black glass, or a glass plate over a sheet of black paper, is laid on the base at *D*. An arm *E* is fixed to the base at an angle of about 35°. *K* supports a Nicol's prism and *L* the object to be studied. Mica cut in different thicknesses gives beautiful color effects. The strained condition of the glass in a pressed bottle stopper can be detected by the appearance of dark spots as the Nicol's prism is rotated.

Questions

1. Make a drawing of a prism, the refractive angle *A* of which is 60°, and trace the path of a ray from *L* as it passes through and out of the prism. Using the same incident ray *L*, increase the angle *A* by 10° successively, and show the change in the emerging ray until it no longer emerges from the side *AC*. Where does the ray emerge?

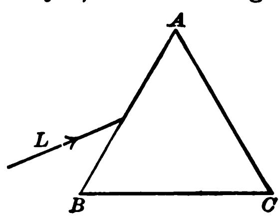


Fig. 523

2. What shape of rainbow might it be possible to see from a balloon?

3. If, in examining with a spectroscope the light from a distant body,

you should find the spectrum continuous, what conclusion would you draw?

4. The velocity of light has been given as 300,000 km. per second. Take the wave length of the red (B) line from the table in § 547, and find how many waves of that color strike the eye per second.

5. In observing the spectrum of a star, the D line was found to be displaced toward the violet end of the spectrum. What is the meaning of the displacement?

6. In pressing two pieces of glass together in a photographic printing frame, a number of groups of colored lines sometimes appear. What is the explanation?

7. The light used in a photographic dark room is a red light. Why?

V. OPTICAL INSTRUMENTS

556. The Simple Microscope is merely a convex lens, usually of short focal length. The object is placed between the principal focus and the lens, and the image is virtual, upright, and larger than the object. If the object AB (Fig. 524) is placed as shown, the position of the image of the point A is determined by the intersection, at A', of aF' and AO. B' is found in a similar way, and the positions of these two points determine the position of the whole image. The distance from the eye to the image is the distance of distinct vision and varies with different eyes.

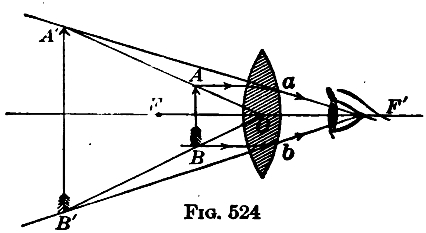


FIG. 524

557. The Compound Microscope (Figs. 525 and 526). — The simplest form of the compound microscope consists of two converging lenses: an *object glass* O and an *eyepiece* E.

The distance between these is so arranged that the object glass forms a real, enlarged, inverted image of the object between the eyepiece and its focus. The function of the

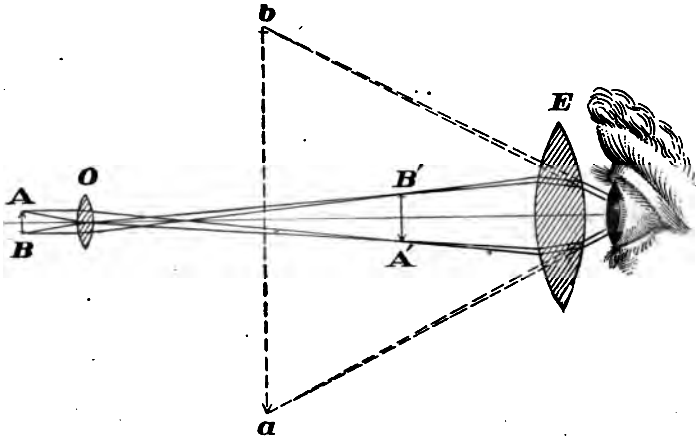


FIG. 525. — Diagram of a Compound Microscope

eyepiece is to enlarge this image, so that the eye sees the enlarged and inverted image at *ab*.

558. The Astronomical Telescope. — The ordinary astronomical telescope (refracting) is much like the compound microscope in principle. But while both lenses magnify in the microscope, owing to the nearness of the object to the object glass, the eyepiece alone magnifies in the telescope. This is due to the fact that the object is at a distance, and the image formed by the object glass is nearly at its principal focus and very small.

559. The Terrestrial Telescope. — The image given by the astronomical telescope is an inverted one. The inverting of the image is not very objectionable when one is looking

FIG. 526. — Compound Microscope and Other Apparatus in a Laboratory for Testing Milk for Bacteria

at the heavenly bodies; but in a telescope to be used on objects on the surface of the earth, it is more convenient to have the image upright. This result is secured usually by putting two converging lenses, at proper distances, between the object glass and the eyepiece.

560. Galileo's Telescope; the Opera Glass. — The simplest, and also the oldest form of telescope is *Galileo's telescope*. This has but two lenses; namely, a convex object glass, and a concave eyepiece (Fig. 527). The eyepiece is placed between the object glass and the image formed by it. Being concave, the eyepiece causes the rays to diverge and appear to the eye to come from *ab*, which thus forms an enlarged upright image. Opera glasses consist of a pair of these telescopes.

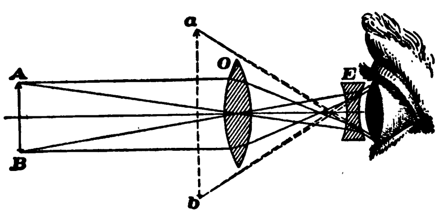


FIG. 527. — Galileo's Telescope

561. The Prism Binocular. — The insertion of the two converging lenses between the object glass and the eyepiece insures an upright image in the terrestrial telescope, but increases the absorption of light. The use of a pair of Porro prisms gives an upright image and shortens the tube of the instrument so that it can be used, in the form of a binocular, as an opera glass. Figure 528 represents such an

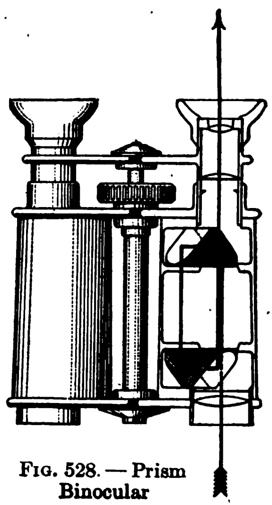


FIG. 528. — Prism Binocular

opera glass, half in cross section. The arrow represents the path of a ray of light through the instrument. This ray is totally reflected from the inner surfaces of the prisms four times.

562. The Optical Lantern is used for the purpose of throwing an enlarged picture of a lantern slide upon a screen. The

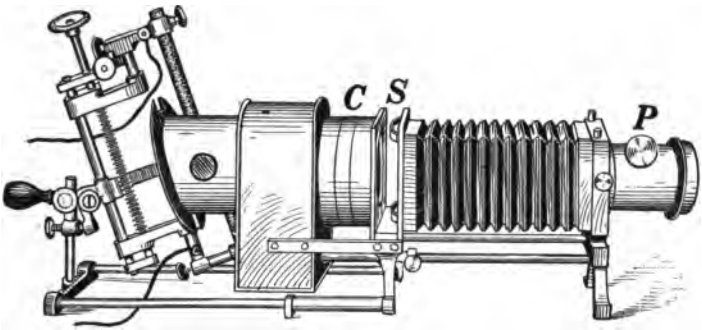


Fig. 529. — Optical Lantern

essential parts are some brilliant source of light, a condensing lens C, formed of two plano-convex lenses with curved surfaces toward each other, a glass lantern slide S, upon which is the picture to be enlarged, and a projecting lens P, a combination of lenses for enlarging the picture. The electric arc is the best artificial light for projection, since the light is intense and its size is small. The lime light, in which a cylinder of lime is raised to incandescence by the heat from an oxyhydrogen blowpipe, is a good light. In cases where the lantern is to be used in a small room, an incandescent lamp with a spiral filament is satisfactory. Such lamps are made to give from 50 to 100 candle power, and are most convenient wherever there is an incandescent circuit.

Book illustrations or opaque objects can be used for projec-

tion instead of lantern slides by directing the light from an arc light or other brilliant source against the picture. An image

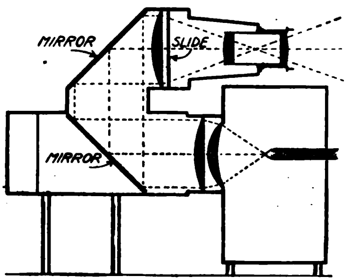


FIG. 530

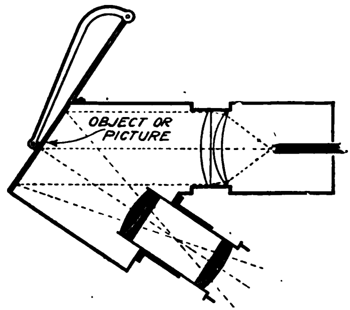


FIG. 531

of this picture is thrown upon the screen by a projecting lens.

Some lanterns, like the balopticon, are so arranged that both lantern slides and pictures can be used. Figure 530 shows the use of two mirrors with the lantern slide. When a picture is to be projected, the lower mirror is raised and the light falls directly upon the picture as in Fig. 531. The complete apparatus is shown in Fig. 532.

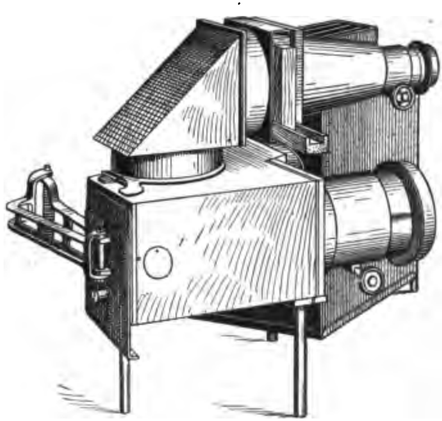


FIG. 532.—Balopticon

The moving-picture machine is a form of lantern used to throw upon a screen in rapid succession a series of pictures taken at intervals of a small fraction of a second. Sixteen pictures per second is the usual number. The retina of the eye re-

tains each image until the next is presented and links them together to show continuous motion. (Figs. 533, 538.)

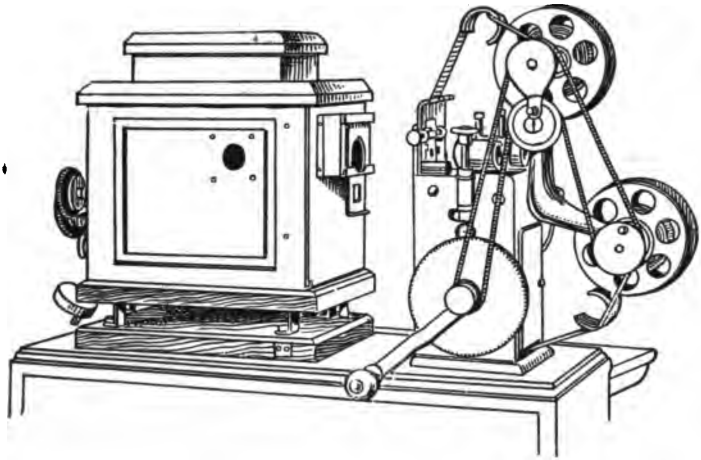


FIG. 533. — Moving-picture Machine

563. The Camera, used in photography, consists of a light-tight box having at one end an achromatic lens and at the other a ground-glass plate and a space in which a plateholder containing a sensitized plate can be placed. In order to regulate the amount of light passing through the lens and to increase the distinctness by cutting off the outside rays, the lens is provided with a series of diaphragms with different-sized openings. The camera is so constructed that the distance

FIG. 534. — Camera

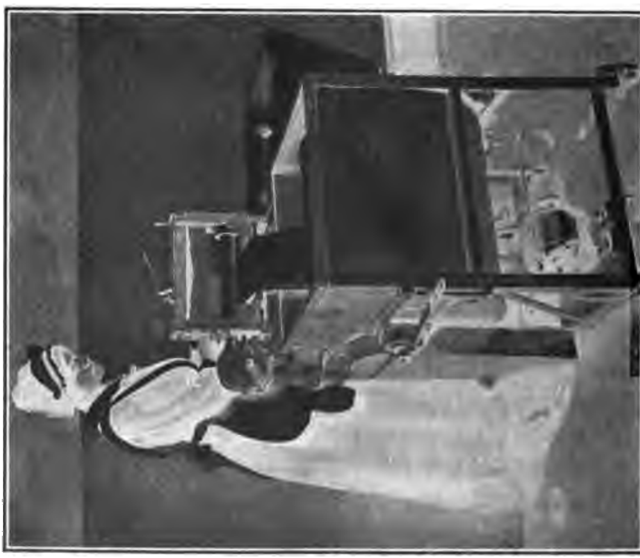


FIG. 535. — Photographic Negative

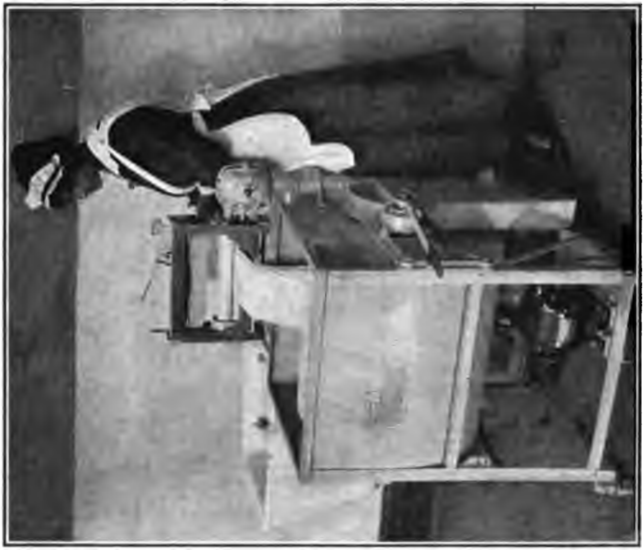


FIG. 536. — Positive Print from Preceding Negative

The washing machine and wringer are operated by the electric motor shown beneath.

between its ends can be varied. By making this the proper distance the image is brought to a focus on the ground glass, then the sensitized plate is put in its place, and the exposure is made.

The plate is afterward *developed* by means of certain chemicals. This process reduces the silver salts in the film to a metallic condition, forming a dark layer wherever the light has acted. The salt that has not been acted upon by the light is dissolved out by putting the plate in a solution of hyposulphite of sodium, after which the plate is washed and dried. The plate is now a *negative* (Fig. 535), and prints can be made from it upon sensitized paper (Fig. 536).

Figure 538 shows a moving picture camera; Fig. 539, a machine for sending a photograph a long distance by wire.

564. The Eye as an Optical Instrument. — The eye is a minute camera, with dark chamber, lens, diaphragm, and

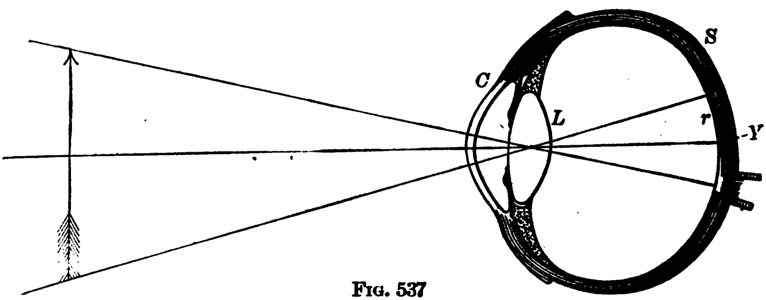


FIG. 537

screen upon which the image is formed. The sclerotic coat *S* (Fig. 518) forms the wall of the dark chamber, and is extended in front as a transparent coat *C* called the *cornea.* The lens *L* of the eye is formed of an elastic, transparent substance, and is called the *crystalline lens.* Extending over the front of the lens is a colored curtain or diaphragm, the *iris*, which determines the color of the eye, and which has

a circular opening in the center called the *pupil.* The image of an object is brought to a focus upon the inner lining *r* of the eye called the *retina,* from which the sensation of sight is carried to the brain by means of the optic nerve. The yellow spot *Y* is the most sensitive part of the retina, and, since it is on the axis of the eye, is the spot on which is formed the image of the point at which the eye looks directly.

We have seen that in the camera the distance between the lens and the ground glass is changed in order to bring a given object to a focus. The distance between the crystalline lens and the retina, however, is a fixed distance, and the focus is obtained by a change in the curvature of the front of the lens, thus changing its focal length. This change of curvature of the lens to change its focus for objects at different distances is called *accommodation.*

565. The Blind Spot. — At the inner side of each eye where the optic nerve enters there is a *blind spot.* This can be readily proved as follows: Close the left eye and look steadily at the cross below with the right. A position can be found in which, while you look steadily at the cross,

+ O

the circle will disappear. When this position is found the circle may be brought into view by moving the book either nearer to the eye or farther away.

566. The Adaptability of the Retina of the eye as a screen for receiving the image formed — because of its concave shape — is shown as follows:

Demonstration. — Fix a convex lens in the shutter of a dark room. Place a white paper screen in such a position that the middle of the image of the landscape will be in focus. The edges

FIG. 538. — MOVING PICTURE STUDIO WITH A CAMERA IN ACTION

Exposures in rapid succession are made by simple mechanism operated by a small crank. Perfect illumination is secured by light from above, combined with banks of mercury vapor lamps (§ 469) at the side.

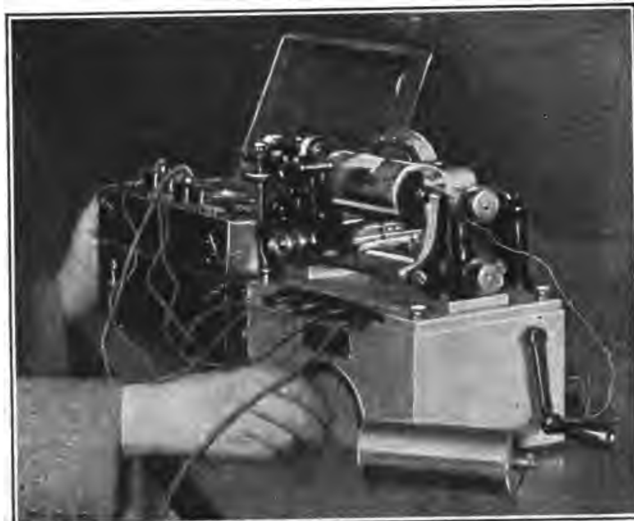


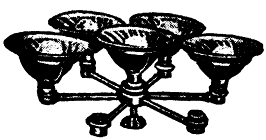
Fig. 539. — The Teleostereograph Transmitter

By this instrument, and a receiving apparatus, photographs can be sent by wire hundreds of miles in a few minutes, and are distinctly reproduced. The transmitting record is a photograph prepared in bas-relief on a revolving cylinder. A stylus connected to a telephone transmitter traces the record, the current varying with the height of the record. This variation in current is transformed at the receiving end into various gradations of a beam of light on a sensitized cylindrical plate, revolving like the first, and from this the picture is developed by the ordinary process. The picture at the left was received in New York from St. Louis by this apparatus in November. 1920.

will be blurred and indistinct. Now bend the screen into the form of a section of the surface of an upright cylinder, and all parts of the picture on a horizontal line will be equally distinct. Turn the screen to other positions and observe the effect.

567. Light and Illumination. — The most important use of artificial light is the illumination of interiors. For interior illumination both the incandescent electric lamp, preferably the tungsten, and the incandescent mantle gas lamp, provide light units that combine convenience and efficiency to a high degree.

Opaque bowl



Interior reflectors

FIG. 540. — Indirect System.

There are three systems of distribution that are used with both gas and electric lighting, the direct, the indirect, and the semi-indirect.

The direct system is one in which the light from the lamp shines directly upon the area lighted, either with or without the help of reflecting shades. This system gives the maximum amount of light for a given expenditure of energy, but is objectionable on account of the glare of the light which either comes directly from the lamp or is reflected from polished surfaces. This objection can be partially overcome by the use of frosted lamps or translucent globes, when it becomes a modified direct system.

The indirect system is one in which the lamps are placed within two or three feet of the ceiling while opaque, bowl-shaped reflectors are placed below the lamps. The inner

surface of the bowls is made of a highly reflecting material and thus the light from the lamp is reflected from the ceiling, from which it is diffused throughout the room. Less light is thrown on a given surface, a table top, for example, for the same expenditure of energy, than in the direct system, but as the eyes are not tired by the direct glare of the light, objects are seen equally well under the reduced intensity. This system does away with the harsh shadows of the direct system, the only shadows formed being soft and pleasing. One form of bowl with interior reflectors is shown in Fig. 540.

The semi-indirect system is one which is intended to com-

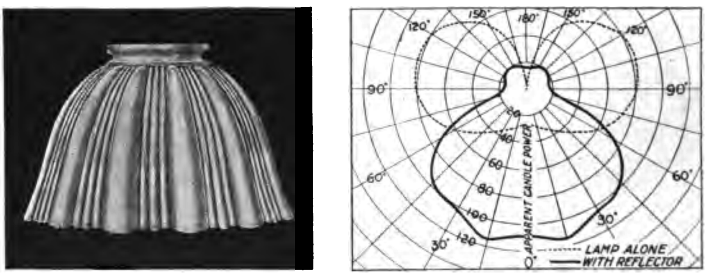


Fig. 541.—Distribution of Light by a Shade

bine the advantages of both the direct and indirect systems and to avoid the objectionable features of each. The method adopted is to reflect a part of the light to the ceiling for general illumination and to direct the rest downward either directly or through translucent screens.

This system has the advantages of lighting a limited area well without concentrating all the light upon it and leaving the rest of the room unlighted.

In order to light a limited area, such as the top of a desk or table, reflecting shades are used. These are of various types, depending upon the character of distribution desired.

Those that light but a small area are called " concentrating " shades, while the " distributing " shade spreads the light over a much larger area.

Figure 541 shows one type of shade and the change in the

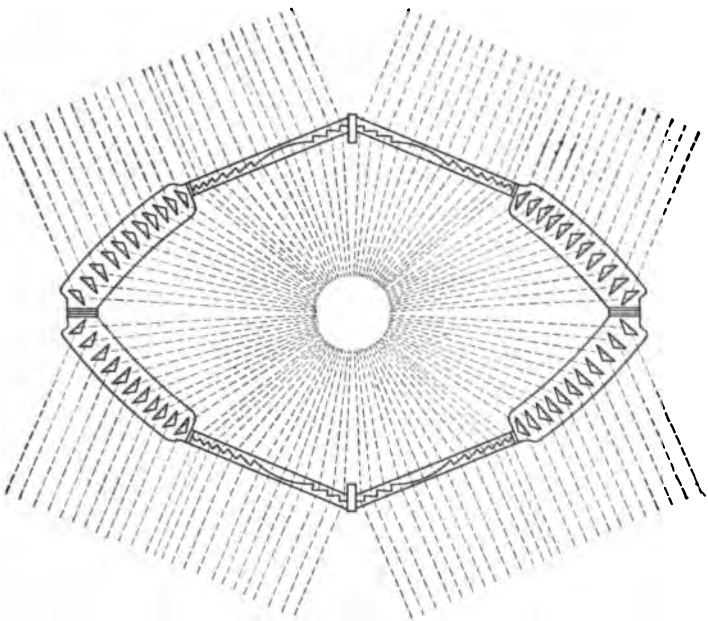


FIG. 542. — Section of Lighthouse Lenses arranged to throw Parallel Rays in Four Directions

distribution made by its use. The dotted curve gives the distribution of light from the lamp without a shade, the radial distance of the curve at any point from the center giving the candle power of the lamp in that direction. The full-line curve shows the distribution when the shade is used, the greater part of the light being thrown downward.

CHAPTER XI

INVISIBLE RADIATIONS

568. Hertz Waves. — We have already seen that a radiometer can be set in motion by invisible *heat rays* (§ 274), and that the sensitized film on photographic paper is affected by invisible radiations of shorter wave length than those of violet light (§ 548). We are now to consider invisible radiations set up by electrical means. If the discharge of a Leyden jar is sent through a metallic circuit and across a short air gap, it will set up a like discharge in the air gap in the circuit of a second similar jar, provided the circuits are parallel and the areas of the circuits are the same. This *electrical resonance* is analogous to the setting of a tuning fork in motion by the vibrations of a similar fork (§ 210). If the forks do not vibrate at the same rate, the second fork will not be put in vibration, and if the area of the second circuit is changed, no spark will appear in the second air gap. The fork is put in motion by waves of air; but electrical resonance is caused by ether waves set up by the spark in the first circuit.

We have seen that the electric spark discharge of a Leyden jar is oscillatory (§ 370). If the image of the spark is observed in a mirror revolving at high speed, it is seen to be a succession of flashes following each other at extremely short intervals.

The velocity of the ether waves set up by electrical oscillations was first determined by Heinrich Hertz in 1888, hence they are known as the *Hertz waves.* This velocity is the same as that of light, 300,000 km. per second. Hertz found that there were 10,000,000 oscillations per second, hence the wave length is 30 m. By reducing the size of the Leyden jar and the length of the circuit, and letting the discharge take place between two balls, the wave length can be made much shorter and the number of oscillations per second much greater.

Silver or nickel filings placed between two metal disks in a glass tube have an extremely high resistance. On the passage of an ether wave sent out by a Leyden jar spark, the filings cohere and offer little resistance. Marconi used this *coherer* as a detector of ether waves in wireless telegraphy, by putting it in a local circuit, containing a sounder or bell, which gave a signal on every passage of a wave from the sending station.

The sending station (Fig. 543) of a wireless telegraph system will, in general, include: a transformer, *A*, or a Ruhmkorff coil, the secondary of which is connected to the spark gap, *B*, the condenser *C*, and the primary helix *D* of an induction coil. The terminals of the spark gap *B* are of zinc and usually inclosed in a glass globe to reduce the noise of the discharge. The secondary helix *E* is grounded at one end and terminates at the other end in the antenna *F*, a wire or

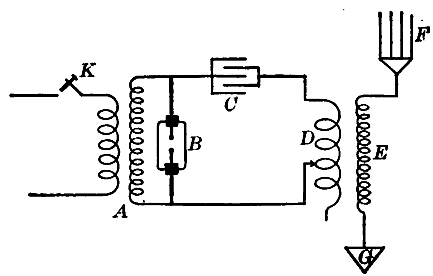


FIG. 543.—Diagram of a Sending Station

group of wires going high into the air. On closing the key K, a spark jumps across B and by properly adjusting the size of the condenser C, the turns of wire in D and E, and the distance between D and E with a given area and elevation of the antenna, the two circuits BCD and EF may be so *tuned* that a maximum of electrical wave energy may be radiated into space from F.

These electric waves, traveling in all directions with the speed of light, may be roughly likened to the waves set up in still water when a stone is thrown into it. Gradually lessening in amplitude, they may be perceived in any direction at a distance which depends upon the sensitiveness of the detector.

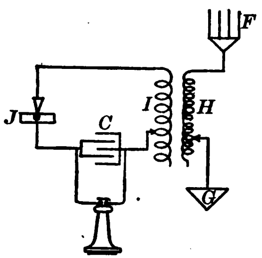


Fig. 544.—Diagram of a Receiving Station

The receiving station for wireless work (Fig. 544) consists of the antenna F, connected to one end of a coil H, the other end of which is grounded; a coil I, movable with respect to H; a detector J; a condenser C, and a telephone receiver.

The feeble electric waves reaching the antenna F, many million times per second, may be heard in the telephone, upon properly adjusting H to F and I to H, as a distinct musical tone every time the key K in the sending station is closed. The very rapid oscillations of the electric waves cannot be detected by the unaided telephone receiver because the diaphragm cannot vibrate fast enough. Hence it is necessary that the detector be so constructed that the train of waves sent out each time the sending key is closed shall be received as an individual signal the length of which depends upon the length of time the sending key is in contact.

Many devices have been developed that will do this with more or less efficiency. One which combines sensitiveness and convenience consists of a contact between two crystals or between a metal and a crystal. Silicon, zincite, bornite, carborundum, and molybdenite have been successfully used.

The action of this type of detector depends upon the fact that the contact between the crystals offers a much greater resistance to the passage of the current in one direction than in the other. Thus one part of the electric wave will produce current through the detector and the telephone, while that part of the wave which is in the opposite direction will produce no current and is unheard.

The form of antenna used depends upon the power of the station. For a small output the straight vertical form is generally sufficient. A flat top is sometimes used with the vertical, as in Fig. 545. For receiving, nearly any metal surface raised above the ground and insulated from it will serve as antenna. Signals from a neighboring sending station may frequently be heard in the receiver of an ordinary telephone system, the wires acting as antenna and the house fuse block as detector.

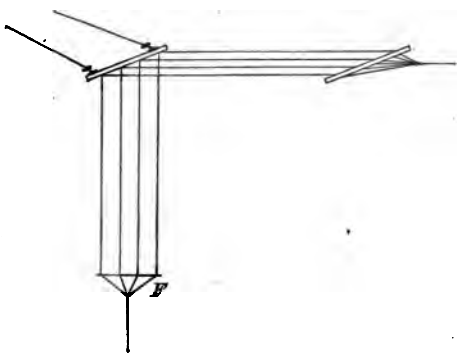


FIG. 545

The invention of the audion for receiving wireless messages has made possible the use of a much smaller aërial than that shown in Fig. 545. The audion consists of a glass

bulb that looks much like an incandescent lamp. It contains, besides a lamp filament, a thin metallic plate and a wire grid, placed between the plate and the filament.

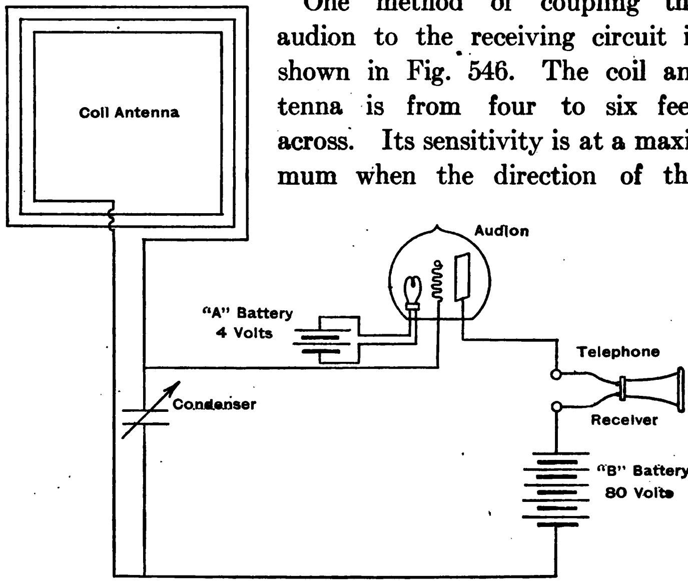


FIG. 546

One method of coupling the audion to the receiving circuit is shown in Fig. 546. The coil antenna is from four to six feet across. Its sensitivity is at a maximum when the direction of the wireless wave is in the plane of the coil; hence, it can be used to locate the direction of the source of the wave if it is mounted on a vertical axis around which it can be turned.

A modified form of the audion serves to amplify the loudness of the signals. By coupling a number of audions in cascade arrangement accurate and clear results are obtained in extreme long distance wireless telephone transmission, such as that in transoceanic communication. The audion is also, for the physical investigator, a tool of the greatest

delicacy, applicable to investigations in many different fields.

569. Cathode Rays. — In considering the luminous effects of the inductive discharge (§ 445) we saw that the spark is longer and much more brilliant in a partial vacuum than in ordinary air. Professor William Crookes made an extensive study of the phenomena of electric discharges in high vacuum tubes. A high vacuum is one in which the gaseous pressure is not more than one millionth of that of the atmosphere. Figure 547 shows the form of tube with which he studied the difference between the phenomena when high and low vacua are used. If the vacuum is low, the discharge shows a curved band of light from the cup-shaped platinum cathode to whichever wire is made the + terminal. If, however, the vacuum is high, the discharge passes from the cathode directly across the globe to the opposite wall, which glows with a yellowish green fluorescence.

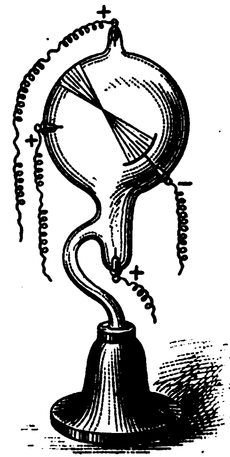


FIG. 547. — Crookes Tube

A study of the action of the cathode rays (§ 570) leads to the conclusion that they consist of a stream of minute, negatively charged particles that are projected from the cathode in a direction perpendicular to its surface, with a velocity about one tenth that of light (Fig. 547).

570. Effects of the Cathode Rays. — (*a*) *The Mechanical Effect.* — In the tube shown in Fig. 548 a light wheel is made

to roll along the glass rails, either to the left or to the right, depending on whether A or B is made the cathode. The rotation of the wheel is caused by the stream of particles sent off by the cathode, which strike the vanes on the top of the wheel.

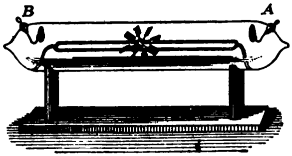


FIG. 548

(*b*) *The Heating Effect.* — The tube shown in Fig. 549 is a focus tube having a thin piece of platinum at the focus of the cup-shaped cathode. The continuous blows of the repelled particles constituting the cathode rays cause this piece of platinum to become red-hot.

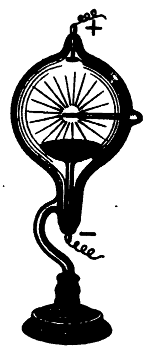


FIG. 549

(*c*) *The Magnetic Effect.* — By using a straight tube and placing a strong electromagnet near one side, as in Fig. 550, it is possible to deflect the rays from their straight path whenever an electric current is sent through the coil of the electromagnet. The fact that the rays are deflected by a magnetic field proves that they are made up of charged bodies, and the direction of this deflection indicates the kind of charge carried.

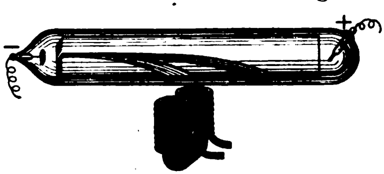


FIG. 550

(*d*) *The Fluorescent Effect.* — The tube shown in Fig. 551 contains, as the anode, a cross of aluminum or mica, hinged to a support at the bottom. When a current is sent through the tube, the bombardment of the cathode rays causes the glass walls of the tube to glow with a fluorescent light except where they are protected by the cross, which

itself receives the bombardment. This shows the straight-line path of the particles. If now the cross is suddenly swung down on its hinge to the bottom of the tube, the part of the tube that was dark before will glow more brightly than the rest. This is due to the fact that the fluorescence fades out after the rays have been striking the glass for some time. The glass may be said to possess a fluorescent fatigue.

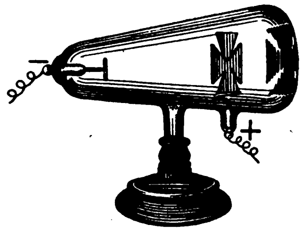


FIG. 551

571. The Röntgen Rays or X–Rays. — Certain luminous tubes, when the secondary current from an induction coil is passed through them, send off rays that make fluorescent substances glow and affect the photographic plate. These rays have, moreover, the property of passing through many opaque substances as rays of light pass through transparent substances. They proceed from that part of the surface of the tube upon which the cathode rays strike, and were called by Professor Röntgen, of Würzburg, their discoverer, *the X-rays*. Unlike the cathode rays, they are not affected by a magnetic field. Unlike light waves, they are not refracted by lenses nor reflected by mirrors. They may perhaps best be described as irregular pulses set up in the ether as a result of the impact of the cathode rays upon the side of the tube.

572. Radiographs. — While the X-rays pass through flesh with very little difficulty, the bones offer much obstruction. This makes it possible to locate the position of the bones by means of X-ray photographs, or *radiographs* (Fig. 552). The

FIG. 552. — Radiograph of a Foot, showing a Broken Needle Embedded in the Flesh

radiographs are of great help to the surgeon in setting a broken bone or in locating a foreign body, as a bullet or needle (Fig. 552). They are of great help to dentists also.

Radiographs are usually made as follows: A photographic plate is inclosed in a plate holder, the object to be radiographed is placed upon the cover of the holder, and the X-rays are directed upon it, from a tube only a few inches away.

Several forms of Crookes tubes (Section 569) are capable of giving off the X-rays. In the forms called *focus tubes* (Fig. 553), the cathode rays are brought to a focus on a platinum plate turned at such an angle that the rays are sent out radially through the glass. Devices are also employed to regulate the vacuum automatically, for otherwise it would become higher with use, until the current would no longer pass.

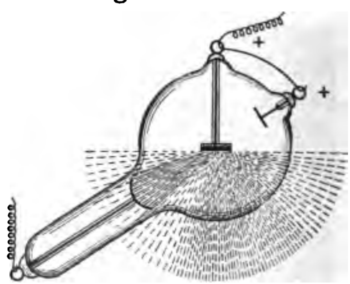


FIG. 553 *X-ray Field*

573. The Fluoroscope, a form of fluorescent screen, was devised by Edison in order that he might study the effect of the Röntgen rays without the use of photographic plates. It consists of a screen covered with crystals of calcium tungstate and fixed to a boxlike support with opaque sides which, opposite the screen, fit so closely around the eyes that they cut off all outside light. By means of the fluoroscope a person may examine, for instance, the bones of his own hand by putting it before the screen and looking through the screen toward a tube that is giving off X-rays.

FIG. 554. — Fluoroscope

574. Radio-activity. — The study of the X-ray and its effects gave rise to the idea that there was a relation between phosphorescence and the X-rays. In 1896 Becquerel found that all the salts of uranium, both those that are phosphorescent and those that are not, emit radiations which affect the photographic plate like the X-ray and pass through thin sheets of metal. Any substance that spontaneously emits radiations like uranium is called *radio-active,* and is said to possess *radio-activity.* Besides uranium, thorium and its compounds are remarkably radio-active. Figure 555 shows the effect produced upon a photographic

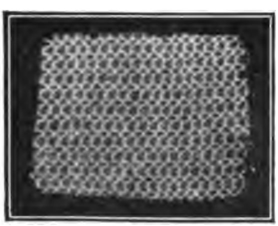


FIG. 555

plate by the radiation from a piece of gas mantle which was placed upon the plate and left in the dark for five days. The gas mantle contains thorium.

Madame Curie examined many substances to determine their radio-activity, and she found that pitchblende, the mineral from which uranium is obtained, is much more radio-active than uranium. She concluded that pitchblende must contain some element more radio-active than uranium, and finally succeeded in separating from it a minute quantity, a few milligrams per ton, of salts of a new element which she called *radium*. Radium chloride has been obtained with a radio-activity *one million times as great as that of the mineral from which it came.*

Rutherford has found in the Becquerel rays three classes of rays: The α-rays (alpha-rays) consist of positively charged particles, having about twice the mass of the hydrogen atom, and a velocity about one tenth that of light. The β-rays (beta-rays) are negatively charged particles, having about $\frac{1}{1770}$ the mass of the hydrogen atom, and a velocity of from 0.6 to 0.96 that of light. They apparently differ from cathode rays in velocity only. The γ-rays (gamma-rays) are believed to be pulses in the ether similar to the X-rays produced in a tube having a high vacuum. Of the three classes of rays the γ-rays have the greatest penetrating power and the α-rays the least. Figure 556 represents rays sent out by a radio-active material, showing the change in direction caused by subjecting them to a strong magnetic field. The α-rays are deflected little, the β-rays much, the γ-rays not at all.

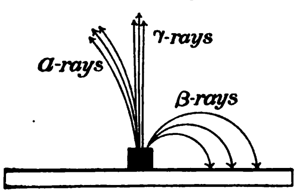


Fig. 556

575. Electrons; Ionization. — When a charged gold-leaf electroscope is surrounded with air in normal condition, it will retain its charge. As soon, however, as X-rays or the radiations from radium fall upon it, it loses its charge and the leaves fall together. To explain this change in the conductivity of the air it is necessary to consider the modern theory of the atom. This is that the atom is a complex structure consisting of minute negatively charged particles in rapid motion, connected with positively charged particles which are themselves in motion. The negatively charged particles are called *electrons*. The velocity with which the α-rays and β-rays leave a radio-active material is probably due to the velocity which the charged particles have within the atom, and which they retain as they leave it. It is supposed that the X-ray pulses separate electrons from the atoms in air. This leaves the air a mixture of negatively charged electrons and positively charged particles, thus making it a conductor, or *ionizing* it.

576. Conclusion. — Since electrons separate from the atoms of radio-active substances it is evident that, however slow the process, there is going on a disintegration or breaking down of the atom. This expulsion from the atom is accompanied by the production of such an amount of heat that the temperature of radium bromide is sometimes as much as five degrees Centigrade above that of the surrounding air. In order to understand the significance of this atomic disintegration it must be followed a step farther. Certain radio-active substances, as radium, actinium, and thorium, emit a substance like a heavy gas that is endowed with temporary radio-active properties. This is called the *emanation*. If kept for a number of days, it loses a large portion of its radio-

activity, and on being examined with the spectroscope, shows the well-defined lines of the element helium, which were not present when the emanation was first formed. This seems to indicate a change from one element into another. Perhaps it is rather an indication that both these elements are but forms of a third and possibly unknown element.

To Dalton belongs the credit of giving the atom its place of honor as the fundamental unit of the chemist. It has taken the combined research of many physicists since Dalton's time to establish the complicated structure of the atom and to show us at least a part of its function in the formation of matter.

APPENDIX

ANSWERS TO NUMERICAL PROBLEMS

Page 33. **1.** 31.58 ft.; 9.63 m. **2.** 1099.08 ft. **3.** 169.16 m **4.** 163.07 m. **5.** 157.5 cm.; 47.17 kg. **6.** 146.93 km. **7.** 210 m. **8.** 3.62 cu. m. **9.** 165 lb ; 74.84 kg. **10.** 907.2 kg. **11.** 9.84 long tons. **12.** 8000 liters; 8000 kg.; 17,636.8 lb. **13.** 88.9 kg. **14.** 14,081.5 lb.

Pages 67–69. **1.** 11.34 mi. per hour; 16.63 ft. per sec. **2.** 65.906 mi. per hour; 96.66 ft. per sec. **3.** As 347,976 : 704,000. **4.** 160.8 ft. per sec.; 402 ft.; 144.72 ft. **5.** 200.8 ft. per sec.; 602 ft.; 184.72 ft. **7.** 2250 ft. **8.** 5 sec.; 24.505 m. per sec. **9.** 36.18 ft. **10.** 24 ft.; 12 ft. per sec. **11.** 196.98 ft. **12.** 5,881,200 dynes. **13.** 72.11 lb. **14.** 442.8 ft. **15.** 38.09 ft. per sec. **16.** 6 ft. **17.** 5.76 ft. from the 36-lb. force; 100 lb. **18** 18,48 lb.; 36.95 lb. **19.** 11.785 mi. **20.** 79.67 ft. per min.; 159.35 ft. per min. **21.** 4 ft.; 2 ft. 8 in. **22.** 54.18 lb.

Pages 78–79. **1.** 7200 ft. lb. **2.** 47,040 ft. lb. **3.** 352 kilogram-meters. **4.** 16 ft. per sec. per sec.; 3482.6 lb. **5.** 1440 ft. lb. **6.** 4142 ft. lb.; 3534 ft. lb.; 608 ft. lb. **7.** 123.5 H. P.; about 92,100 watts. **8.** 14,000 ft. lb.; 8000 ft. lb.; 14,000 ft. lb. **9.** 115,200 ft. lb.; 1.16 H. P.; 115,200 ft. lb. **10.** 41 min. 11 sec. **11.** 320 H. P. **12.** 11.52 H. P. **13.** 4.77 sec.; 153.43 ft. per sec.; 1830 ft. lb.

Page 89. **1.** 7.2; 7.68. **2.** 80 lb. **3.** 1.5 ft.; 1.6 ft. from center of 10-lb. ball. **4.** .92 ft. from middle toward heavier boy. **5.** 3. ft. **6.** 4.54 cm. from weight. **7.** 300,000 ft. lb. **8.** 8482.8 ft. lb.

Page 96. **1.** 223.46 cm. **2.** 1.108 sec. **3.** 99.305 cm. **4.** 99.289 cm. **5.** 981.82.

Pages 114–118. **1.** 90%. **2.** 86.6%. **3.** 2.4 in. **5.** 7.75 ft. to right of F. acting upward; 136 lb. by lever downward and 136 lb. by F. upward. **6.** 17.86; 138 lb. **7.** 13.3 lb. **8.** 41.6 lb. **9.** 25 lb. **10.** 19; 1425 lb. **11.** 880 lb. **12.** 10.55 lb. **13.** 5.5 in.

14. 800 lb. **15.** 104.72 ft. per sec. **16.** 63.66. **17.** 5.5 : 1. **18.** 20 in. **19.** 48.83 lb.; 640 ft. **20.** 550 lb.; 12 ft. **21.** 104 kg.; 18 m. **22.** 7; 89.14 kg. **23.** 36 lb. **24.** $916.\dot{6}$ lb. **25.** 598 lb.; 1.8 H. P. **26.** 24 H. P. **27.** 1759.3 lb. **28.** $\frac{1}{120}$ in. per sec.; 2.094 in. per sec. **29.** $\frac{1}{4}$ in. or $1\frac{3}{4}$ in. **30.** 22,619.52 lb.; 0.398 in. **31.** 4.7%. **32.** 36%. **33.** 12.5%.

Page 129. **1.** One half as great. **2.** 0.04 mm. **3.** 418.5 ft.

Pages 143–146. **1.** 13,920 lb. **2.** 5.39 sq. in. **3.** 10,584 lb. **4.** 90,000 lb. **5.** 17.36 lb. **6.** 35,437.5 lb. **7.** 160 g.; 2176 g. **8.** 63,281.25 lb.; 63,281.25 lb. **9.** 99.8 lb. **10.** 100,473+ gal.; 419.73 tons; 846.66 tons; 6250 lb. **11.** 4057.9 lb.; 15. **12.** 6406.25 lb. **13.** 2.38 kg. **14.** 84,375 lb. **15.** $20.8\dot{3}$ lb. **16.** 8 ft. from top. **17.** 10 ft. from top. **18.** 480 kg.; 360 kg.; 288 kg. **19.** 8584 kg.

Pages 154–156. **1.** 1005.4 cu. in.; 1580 cu. in. **2.** 187.5 lb.; 62.5 lb.; 43.75 lb.; 43.75 lb. **3.** 3.84 in. **4.** 229.25 lb. or 229.2 lb.*; 1.328 in. **5.** 8.43 ft. **6.** 0.96 in. **7.** 165.7 tons. **8.** 2.35. **9.** 8.6; 8.6. **10.** $1.6\dot{6}$; 200 g. **11.** 21.568 or 21.59.* **12.** 2.69 lb. **13.** 113.59 lb. or 113.36 lb.* **14.** 2.61.; 163+ lb. per cu. ft. **15.** 2 cu. ft. **16.** 3434.4 lb.; 565.6 lb. **17.** 500 g. **18.** 42.9 g.; 15.7 g. **19.** 331.8 cu. in. **20.** 0.772. **21.** 0.916. **22.** 0.001293 g. per c.c. **23.** 1.032. **24.** 0.88; 55 lb. **25.** 116 lb.

Pages 189–190. **1.** 375.7 g. per sq. cm. **2.** 50,803.2 lb. **3.** 55 cu. ft. **4.** One fifth. **5.** 33.87 ft. **6.** 98.6 lb. **7.** 20 cu. ft. **8.** $5\frac{1}{3}$. **9.** 10,584 lb. **10.** 17,733.7 ft. lb. **11.** 33.77 ft. **12.** 8125.23 mm.; 10.79 mm. **13.** 20 in. **15.** 3.4 atmospheres. **16.** 0.0135 atmosphere. **17.** 32.97 ft. **18.** 0.68 g. **19.** 13.35 lb. per sq. in. **20.** 67.7 lb. **21.** 306.45 kg.

Page 202. **1.** 1135.2 ft. or 1136.5 ft. **2.** 3389.27 ft. or 3391.5 ft. **3.** 558.88 ft. or 559.25 ft. **4.** 844.05 ft. or 844.87 ft. **5.** 7.5 sec. nearly. **6.** 10,692 ft. or 10,701.9 ft. **7.** 2824.4 ft. or 2826.25 ft. **8.** 3377.7 ft. or 3379.5 ft.; 16,888 ft. per sec. or 16,897.5 ft. per sec. **9.** 4.3+. **10.** 12,491 ft. nearly or 12,501.5 ft.

Page 220. **1.** 50 in. **2.** 8.52 in. **3.** 329.34 m. **4.** 2. **5.** 255. **6.** 16. **8.** 330+; 310 nearly.

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* Differing answers possible with different methods of solution, because the weight 62.5 lb. per cu. ft. of water, and the numbers in table on p. 150, are only approximate values.

Page 236. **1.** 66.6 cm. **3.** 75; 300. **4.** 100; 88.8; 80; 75; 66.6; 60; 53.3; 50. **5.** 12 ft.; 6 ft. **6.** 12.8 in. **7.** 256. **8.** 44.4 cm.; 64 cm. **9.** 0.212 in.; 0.847 in. or 0.848 in.

Page 246. **1.** 45°. **2.** 15°. **3.** 77° F. **4.** −2.7° C. **5.** −40°. **6.** 36.8° C. **7.** 24.4° C. **8.** −313.96° F. **9.** 2768° F. **10.** 9.4° C.

Page 280. **1.** 0.1045 in. **2.** 0.000016. **3.** 0.04176 mm. **4.** 1.09 cu. ft. **5.** 3689.2 cu. ft. **6.** 457.2 c.c. **7.** 146.25 c.c. **8.** 4.097 kg. **9.** 57.75° C. **10.** 168° C. **11.** Air at 23° C. **12.** 8.9 g. **13.** 58%. **14.** 13.505 g.; 16.881 g.; between 19° C. and 20° C.

Pages 286–287. **1.** 17,000. **2.** 810. **3.** 0.1086. **4.** 9.36 g. **5.** 7.52 g. **6.** 17.12 g. **7.** 36.4° C. **8.** 88.9° C. **9.** 51.8° C. **10.** 1.77 kg. **11.** 12.5 min. **12.** 11,520. **13.** 960. **14.** 11,066.6 cal. **15.** 42 min. 57.6 sec. **16.** 131.63 g. **17.** 28,680 cal. **18.** 157.89 g. **19.** 90,000.

Page 299. **1.** 105,000. **2.** 18° F. **3.** 2.78 lb. **4.** 3.21°. **5.** 7068.6 ft. lb.; 14,137.2 ft. lb.; 1,498,543.2 ft. lb.; 45.4 H. P.

Page 317. **1.** 10,000. **2.** −pole; 240 maxwells. **3.** 533.3 dynes. **4.** 2513.28 maxwells. **5.** 750 gausses.

Pages 361–362. **1.** 16.87 ohms. **2.** 102.52 ohms. **3.** 135.26 ohms. **4.** 1.359 amp. **5.** 1.177 amp. **6.** 0.5 amp. **7.** 0.127 amp. **8.** 0.195 amp. **9.** 0.151 amp. **10.** 1.875 amp. **11.** 0.592 amp. **12.** 0.3 ohm.

Pages 379–380. **1.** 349,920 cal. **2.** 594,000 cal. **3.** 4,356,000 cal.; 110 volts. **4.** 35,700 cal. in the copper, 216,954 cal. in the iron. **5.** 95.12° C.

Pages 392–393. **1.** 1.89 volts; 2.835 volts; 4.725 volts; 5.67 volts. **2.** 12.2 ohms. **3.** 4.5 ohms. **4.** 1.222 amp.; 0.846 amp.; 2.068 amp.; 5.32 ohms. **5.** 220 ohms; 55 ohms; 110 ohms; $73.\dot{3}$ ohms; 55 ohms; 44 ohms; 44 ohms. **6.** 660; 29.7 cents. **7.** $1.4\dot{4}$ ohms. **8.** 19.5 ohms; 11 lamps. **9.** 2.42 ohms.

Page 418. **1.** 9.5 volts. **2.** 37.5 amp. **3.** 75 amp. **4.** 1800 r. p. m.; 120 alternations per sec. **5.** 11,000,000. **6.** 12,000,000.

Pages 433–434. **1.** 11.25 ohms; 16.25 ohms. **2.** 5 ohms; $7.\dot{2}$ ohms; $2.\dot{2}$ ohms; 9 amp. **3.** 2.25 in. for + carbon; 1.125 in. for − carbon. **4.** 16.5 ohms. **5.** 600 volts; 9.6; 62.5 ohms; 4.17 ohms. **6.** $17.\dot{7}$ ohms; $6.\dot{6}$ ohms. **7.** 7.33 ohms; 41,250 watts. **8.** 0.4 ohm; 21,555.5 c. p. **9.** 747.5; 455; 10.77 ohms; 6.92 ohms; 61%.

10. 0.364 amp.; 0.545 amp. **11.** 5.46 amp.; 6.54 amp.; 1.08 amp. **12.** 110 volts; 0.327 amp.; 336.4 ohms; 518 cal. **13.** 128.6 amp. **14.** 0.0025 ohms; 144,000 cal. **15.** 53 lamps. **16.** 8.453 amp.

Pages 442–443. **1.** 5 in. **2.** 62.5 ft. **3.** 1.28 sec. **4.** 8 min. 18 sec. **5.** 35 min. nearly. **6.** About 1245 days. **7.** 1.45 m. **8.** 9.19 m. **9.** 256 c. p. **10.** Incandescent lamp is 2.77 times as bright as kerosene lamp.

Pages 456–457. **1.** 19°. **2.** 50°. **3.** 12 ft. **4.** ½ in **5.** 1.5 in. **6.** 2 ft. **7.** 3 ft.; 9 in.

Page 473. **1.** 4.5 in. **2.** 9 in. **3.** 3.2 in. **4.** 0.2 in. **5.** 4.8 in.; 1 : 4. **6.** 60 cm.

Table of Conversion Factors

To Change	To	Multiply by
Inches	Centimeters	2.54
Feet	Meters	0.3048
Miles	Kilometers	1.60935
Meters	Inches	39.37
Meters	Feet	3.28083
Kilometers	Miles	0.62137
Square inches	Square centimeters	6.4516
Square feet	Square meters	0.0929
Square yards	Square meters	0.8361
Square centimeters	Square inches	0 155
Square meters	Square yards	1.196
Cubic inches	Cubic centimeters	16.3872
Cubic yards	Cubic meters	0.7646
Cubic centimeters	Cubic inches	0.06102
Cubic meters	Cubic yards	1.308
Fluid ounces	Cubic centimeters	29 574
Quarts	Liters	0.9464
Cubic centimeters	Fluid ounces	0.0344
Liters	Quarts	1.0567
Grains	Milligrams	64.7989
Ounces (Avoirdupois)	Grams	28.3495
Pounds (Avoirdupois)	Kilograms	0.4536
Ounces (Apothecary)	Grams	31.1035
Pounds (Apothecary)	Kilograms	0.3732
Grams	Grains	15.4324
Kilograms	Pounds	2.2046
Kilowatts	Horse Power	1.34
Horse Power	Kilowatts	0.746
B. T. U.	Calories	252
Calories	B. T. U.	0.3968

(For page 63)

The fact that the acceleration given by F_c is $\frac{v^2}{r}$ can be obtained from a consideration of Fig. 557. Suppose a body of mass M to be moving around the circle whose center is O, with a uniform velocity v. The space AB, over which it passes in the time t, is $S = vt$. (Formula 2, page 37.) Let the time t be taken as a very short time — so short that the arc AB is practically equal to the chord AB. On AB as a diagonal, complete the rectangle $ADBC$. The distance the body is drawn away from AC toward O, by the constant centripetal force, is practically equal to

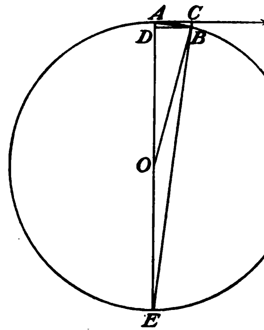

Fig. 557

$$CB = AD = \tfrac{1}{2}\,at^2. \quad \text{(Formula 4.)}$$

Now, by geometry,* $\overline{AB}^2 = AD \times AE,$

or $v^2t^2 = \frac{1}{2}\,at^2 \times 2\,r.$

Hence $v^2 = ar$, and $a = \frac{v^2}{r}.$

(For page 462)

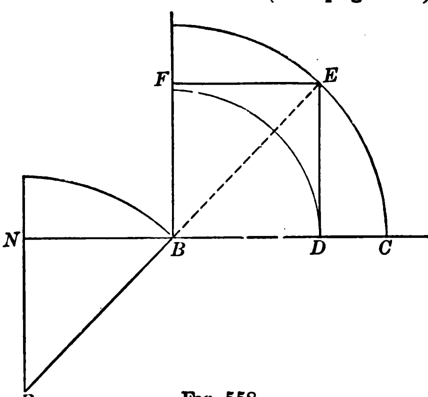

Fig. 558

Fig. 481 shows how the direction of a ray, leaving water, may be traced into air.

When the angle of incidence NPB, Fig. 558, is the critical angle, the angle of refraction, FBC, must equal 90°. This will be true when NB multiplied by four thirds, the index of refraction, equals the radius PB or BC.

From the similar triangles NPB and FBE, $NB = FE$.

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* AE is the hypotenuse of the right-angled triangle ABE, and BD is a perpendicular dropped upon it from the vertex of the right angle.

BD also equals FE. Hence $BD = NB$, and since $BC = \frac{4}{3}$ of BD, it also equals $\frac{4}{3}$ of NB; that is, four thirds of NB equals the radius, and the angle NPB is the critical angle.

The mathematical term for NB, when the radius PB equals unity, is the sine of the angle NPB; hence the critical angle is that angle, the sine of which multiplied by the index of refraction equals unity, or the sine of 90°.

FORMULAS

Page	Subject	Formula	Number
19	Elasticity	$e = \dfrac{\text{Stress}}{\text{Strain}}$	1
37	Motion (average speed or velocity)	$S = vt$	2
38	Accelerated Motion	$v = at$	3
38		$S = \frac{1}{2}at^2$	4
38		$v = \sqrt{2aS}$	5
39		$s = \frac{1}{2}a(2t - 1)$	6
	Falling Bodies:		
43	From position of rest	$v = gt$	7
43		$s = \frac{1}{2}g(2t - 1)$	8
43		$S = \frac{1}{2}gt^2$	9
44	With initial velocity	$v = V + gt$	10
44		$s = V + \frac{1}{2}g(2t - 1)$	11
44		$S = Vt + \frac{1}{2}gt^2$	12
47	Momentum	$b = Mv$	13
47	Force in Absolute Units	$F = Ma$	14
48		$W = Mg$, or $M = \dfrac{W}{g}$	15
49	Force in Gravity Units	$F = \dfrac{Wa}{g}$	16
63	Centrifugal Force	$F_c = \dfrac{Mv^2}{r}$	17
63		$F_c = \dfrac{Wv^2}{gr}$	18
71	Energy	$P.E. = Wh$	19
71		$K.E. = \frac{1}{2}Mv^2$	20
72		$K.E. = \dfrac{Wv^2}{2g}$	21
74	Work	$\text{Work} = FS$	22
77	Horse Power	$\text{No. H.P.} = \dfrac{\text{No. foot pounds}}{33{,}000 \times \text{No. minutes}}$	23

Page	Subject	Formula	Number
80	Mutual Attraction	$F_g = \frac{Mm}{d^2} a$	24
82	Weight above Surface of Earth	$W : w = d^2 : D^2$	25
91	Simple Pendulum	$t = 2\pi\sqrt{\frac{l}{g}}$	26
92		$t : t' = \sqrt{l} : \sqrt{l'}$	27
97	Efficiency	$E = \frac{W_u}{W_t}$	28
97	General Law of Machines	$Pd = RD$	29
100	Lever	$P : R = R.$ arm : $P.$ arm	30
103	Wheel and Axle (power applied to wheel)	$P : W = r : R$	31
105	Fixed Pulley	$P = W$	32
105	Movable Pulley	$P = \frac{1}{2} W$	33
106	System of Pulleys	$P = \frac{W}{n}$	34
	Inclined Plane:		
108	Power parallel to L	$P : W = H : L$	35
110	Screw	$P : W = p : 2\pi R$	36
111	Coefficient of Friction	$f = \frac{P}{W}$	37
135	Liquid Pressure	$P = HaW$	38
149	Specific Gravity of Solids	Sp. gr. $= \frac{W}{W - W'}$	39
178	Boyle's Law	$PV = P'V'$	40
199	Velocity of Sound in Air	$v = 332.4\sqrt{1 + 0.003665\,t}$	41
199	Velocity of Sound in Any Medium	$v = \sqrt{\frac{e}{d}}$	42
205	Velocity and Wave Length	$v = NL$	43
206	Velocity from Resonance Tube	$v = 4\,N(l + 0.4\,d)$	44
242	Thermometer Readings	$\mathrm{C} = \frac{5}{9}(\mathrm{F} - 32°)$	45
242		$\mathrm{F} = \frac{9}{5}\,\mathrm{C} + 32°$	46
242		$\frac{\mathrm{C}}{100} = \frac{\mathrm{F} - 32}{180}$	47
260	Linear Expansion	$L' = L(1 + Kt)$	48
265	Laws of Boyle and Charles	$\frac{PV}{T} = \frac{P'V'}{T'}$	49
282	Specific Heat	$Mts = M't's$	50

Page	Subject	Formula	Number
321	Electrical Attraction or Repulsion	$f = \pm \frac{Qq}{d^2}$	51
327	Electrical Capacity	$C = \frac{Q}{V}$	52
355	Resistance of Wire	$R = K\frac{l}{d^2}$	53
357	Ohm's Law	$I = \frac{E}{R}$	54
	Currents sent from Generators:		
358	In series coupling	$I = \frac{SE}{Sb + R}$	55
359	In parallel coupling	$I = \frac{E}{\frac{b}{P} + R}$	56
359	In series and parallel	$I = \frac{SE}{\frac{Sb}{P} + R}$	57
363	Heating Effects of Current	$H = 0.24\ I^2Rt$	58
390	Combined Resistance of Parallel Circuits	$R = \frac{gs}{g + s}$	59
414	E.M.F. of Dynamo	$E = \frac{nCN}{10^8}$	60
441	Light Intensity	$L = S\frac{d'^2}{d^2}$	61
454, 470	Concave Mirrors, Convex Lenses	$\frac{1}{F} = \frac{1}{D_0} + \frac{1}{D_i}$	62

DEFINITIONS

Absolute Zero: a temperature that is 273° Centigrade below the Centigrade zero, *i.e.*, $-273°$ C.

Acceleration: the increase per second in the speed of a moving body for each second of its movement.

Achromatic Lens: a lens that forms an image of an object without colored edges.

Actinic Rays: spectrum wave lengths shorter than the violet.

Adhesion: molecular attraction between molecules of different kinds.

Agonic Line: a line drawn through all places at which the needle points true north.

Ammeter: an instrument for measuring an electric current in amperes.

Amplitude: the greatest distance that a vibrating body goes from its position of rest.

Aneroid Barometer: a form of barometer in which no liquid is used.

Anode: the electrode by which the current enters an electrolyte in the electrolysis of metals.

Athermanous: without heat.

Atom: the smallest particle of an element which can either exist alone or enter into the composition of molecules.

Barometer: an instrument for measuring the pressure of the atmosphere.

Beats: rhythmical variations in the intensity of sound, alternately strong and weak.

Boiling Point: the temperature at which a liquid passes into the air in molecular form, under atmospheric pressure.

British Thermal Unit: the amount of heat required to raise the temperature of one pound of water 1° F.

Buoyancy: the lifting power of a liquid upon a body submerged in it.

Calorie: the amount of heat required to raise the temperature of one gram of water one degree Centigrade.

Calorimetry: the measurement of heat.

Capillary Attraction: the attraction that causes a liquid to rise in a tube.

Cathode: the electrode by which the current leaves an electrolyte.

Centigrade Scale: a temperature scale which makes the freezing point of water 0° and its boiling point 100°.

Centrifugal Force: the force that causes the parts of a rotating body to tend to fly from the center.

Centripetal Force: the force that prevents the parts of a rotating body from flying from the center.

Chord in Music: tones that harmonize.

Chromatic Scale: a scale formed of the thirteen semitones in an octave.

Cohesion: the attraction between particles of the same kind at molecular distances.

Commutator: a device that changes the direction of every other half wave of an alternating current, thus producing a direct current.

Convection: the rising of heated air or liquid setting up a convection current.

Critical Temperature: the temperature above which no pressure however great can reduce a gas to a liquid.

Crystallization: the formation of crystals on passing from a liquid to a solid state.

Declination: the angle between the direction the magnetic needle points and the true north and south direction.

Density: the quantity of matter in unit volume.

Dew Point: the temperature at which moisture in the atmosphere condenses to liquid water.

Diffraction: the bending of a ray of light on passing the thin edge of an opaque body.

Dip: the departure of a magnetic needle from a horizontal position.

Ductility: the property by which a body can be drawn out into a thread.

Dyne: the absolute unit of force that acting upon one gram of mass will give it an acceleration of one centimeter per second per second.

Efficiency: the ratio of output to input in a machine.

Elasticity: the property which enables a body to regain its original size and form after being elongated, compressed, bent, or twisted.

Electrolyte: a compound subject to decomposition by an electric current; in solution it conducts the current from one electrode to another.

Electrons: particles smaller than the atom.

Electroscope: an instrument for determining the electric charge of bodies.

Energy: the power of doing work.

Equilibrant: a force opposite in direction and equal in amount to the resultant of two or more forces.

Erg: the work done by a force of one dyne moving one centimeter.

Evaporation: the passing of a liquid into the air by the escape of its molecules, chiefly on account of a rise in the temperature of the liquid.

Fahrenheit Scale: the temperature scale in which the freezing point of water is 32° and its boiling point 212°.

Focus: the point to which rays of light, heat, etc., converge.

Foot Pound: the gravity unit of work. The work done in raising one pound vertically against the force of gravity.

Force: that which tends to produce, to change, or to destroy the motion of a body.

Fraunhofer Lines: Dark absorption lines in the solar spectrum.

Freezing Point: the temperature at which a liquid solidifies.

Friction: the resistance that is encountered in moving (or trying to move) one body over another under pressure

Galvanometer: an instrument that shows the electric current passing through it by the deflection of its needle.

Gram: the weight of one cubic centimeter of pure water at 4° Centigrade. The physical unit in the C. G. S. system.

Graph: a curve showing the continuous relation between two series of physical changes.
Grids: the plate electrodes of a storage cell.

Hardness: resistance to wear by friction.
Horse Power: a rate of work of 33,000 foot pounds per minute.
Humidity: the condition of the air with respect to the amount of moisture in it.
Hydrometer: a floating instrument for determining the specific gravities of liquids.

Impenetrability: a property of matter that prevents two bodies occupying the same space at the same time.
Incidence, Angle of: the angle between a ray of light and the perpendicular to the surface on which it strikes.
Inertia: the tendency of a body to retain its condition of rest or motion.
Insulator: a substance that does not carry a current of electricity.
Interference: when the trough of one series of waves meets the crest of another series.
Isochronous: uniform in time; vibrations made in the same time are isochronous.

Joule: a unit of work equal to 10,000,000 ergs.

Kilogram: 1000 grams.
Kinetic Energy: the energy of motion.

Lactometer: a form of hydrometer used for testing milk.
Liter: a unit of liquid capacity, a cubic decimeter.
Lycopodium Powder: the spores from a certain class of plants.

Machine: a mechanical device for applying force advantageously.
Magnetic Field: a space occupied by magnetic lines of force.
Malleability: the property that allows a body to be rolled or beaten into thin sheets.
Manometer: a device for measuring gas pressure.
Maxwell: a line of magnetic force.
Meter: the ten millionth part of the quadrant of the earth. The C. G. S. unit of length.
Mil: the thousandth part of an inch.
Molecule: the smallest division of matter that retains its identity.
Moment of a Force: the product of the force by its lever arm,

Node: the place of no vibration in a cord producing static waves.

Octave: the eighth tone of a scale having double the number of vibrations of its fundamental.

Osmose: the passage of a liquid through a porous membrane.

Plane Mirror: a plane totally reflecting surface.

Plane Polarized Light: light formed by vibrations that are parallel to each other.

Plumb Line: a vertical line.

Polariscope: a device for the study of substances by polarized light.

Porosity: a property possessed by a body in which the particles that compose it do not fill its entire volume.

Relay: a high resistance electromagnet in series with the main line in a telegraphic system.

Resistance: that which opposes the passage of an electric current through a conductor.

Rheostat: a resistance box for commercial use.

Semitone: the interval between a tone and its sharp.

Specific Gravity: the relative weight of a body compared with the weight of an equal volume of water.

Specific Heat: the number of calories required to change the temperature of one gram of a substance one degree Centigrade.

Spectrum: the group of wave lengths into which a beam of light is separated by a prism or by a diffraction grating.

Strain: the change of shape or size produced when a body is under a stress.

Stress: a force bearing upon a body and tending to change its size or shape.

Tenacity: the resistance of a body to being pulled apart.

Thermostat: a device for announcing when the temperature of a room is too hot or too cold.

Vacuum: a space exhausted of air or gas.

Vapor: gaseous matter, of a substance that is liquid at normal temperature and pressure.

Volt: that electrical pressure that will send one ampere of current through one ohm of resistance.

Watt: one Joule of power per second. $\frac{1}{746}$ of a horse power.

SUPPLEMENTARY QUESTIONS AND PROBLEMS

I. States and Properties of Matter.

1. Define a solid, a liquid, a gas. Explain the kinetic theory of matter as applied to each.

2. State the difference between general and specific properties of matter. Name and define several general and several specific properties.

3. Define and give an example of mass, weight, force. Name the unit of each.

4. Write the value of μ (one micron) in millimeters.

II. Motion, Velocity, and Force.

1. On December 12, 1920, Lecointe, a French aviator, broke the airplane speed record by flying 4 kilometers in 46 seconds. What was his speed in feet per second, in miles per hour, in kilometers per hour?

2. An airplane one mile high traveling at the rate of 90 mi. per hr. drops a bomb when directly over the high school. How far from the building would the projectile strike the ground if its course were not affected by the resistance of the air?

3. A photograph of a luminous bomb dropped from a horizontally moving airplane was made at night and the path differed slightly from the path shown in Fig. 15. Mention two possible reasons for the difference.

4. A boat is rowed across a river heading in a direction at a right angle to the current with twice its speed, landing on the opposite bank 1.5 miles downstream from the starting point. Find the width of the river and the distance the boat traveled. Make a diagram of its path to scale.

5. Two boys fasten ropes to the bag on second base of a baseball diamond. One pulls toward the first base and the other toward the third base, each pull being 25 lb. What must be the amount and direction of a pull that will hold the bag in place? Make a diagram to scale.

6. An airplane whose speed is 85 mi. per hr. in still air drives into a head wind that retards it 25 mi. per hr. It then turns and goes with the wind. Then it heads in a direction at a right angle to the wind. Find the velocity of the plane in each case. Make a diagram for each to scale.

7. Give the relative tendency of an automobile to skid at velocities of 20 and 30 mi. per hr. as compared with a velocity of 10 mi. per hr.

III. Energy and Work.

1. A 3-lb. projectile has a velocity of 2000 ft. per sec. What kind of energy has it? How much? What would be the effect of doubling its velocity? of doubling its weight?

2. If we make no allowance for the resistance of the air, how high would the projectile of problem 1 go if fired vertically upward with the same velocity? What would be its potential energy at the top of its path? What would be its kinetic energy on striking the ground? What would be its velocity on striking the ground?

3. It requires a force of 396 lb. to move an automobile over a level road. How much work will be done in moving it 5000 ft.? What horse power will be required to do it in 3 minutes?

4. A constant pull of 470 lb. is required to move a loaded truck at the rate of 20 mi. per hr. What horse power does the motor develop?

IV. Machines.

1. What is meant by the efficiency of a machine? Why is it always less than 100%? Explain this with reference to some especial machine.

2. A down pull of 25 lb. applied 10 ft. from a fulcrum balances a weight of 150 lb. How far from the fulcrum is the weight placed? What class of lever is it?

3. A weight of 750 lb. placed 1.5 ft. from a fulcrum is balanced by a lift at the end of a lever arm 12.5 ft. long. What is the amount of the lift? What class of lever is it?

4. A crank 18 in. long is used to turn an axle 5 in. in diameter. A rope 1 in. in diameter is wound around this axle and a bucket holding a cubic foot of water is attached to this rope and is raised from a well. What force must be applied to the handle to balance the weight of the water?

5. Find the coefficient of friction between a sled runner and snow when it takes a pull of 24 lb. to draw a boy and sled weighing 136 lb.

V. Liquids.

1. A cubical block of wood is loaded so that it will sink in water with its top in the surface of the water. What keeps it from sinking? Why does it not move to one side?

2. How much water will a block of pine wood displace? How much will a block of marble displace?

3. What is the density in grams per c.c. of a body the specific gravity of which is 2.57? What is its density in pounds per cu. ft.?

4. An empty bottle weighs 64.7 grams. The weight of the bottle full of water is 278.5 grams. The weight of the bottle full of alcohol is 239.8 grams. Find the specific gravity of the alcohol.

VI. Gases.

1. How does the motion of the molecules in a gas differ from that in a liquid or a solid ?

2. What determines the buoyant or lifting force of the atmosphere on a balloon? Is there any limit to the height to which a balloon will rise? Why?

3. Why is mercury used in making a barometer ?

4. To what height will a suction pump draw water? To what height will a force pump force it ?

VII. Sound.

1 Give examples to show that sound is transmitted through solids, liquids, gases.

2. Under what conditions will a vibrating body produce a musical tone ? What is the difference between a musical tone and a noise ?

3. Why is the tone of an open pipe an octave lower than the tone produced by the same pipe when the end is closed ?

VIII. Heat.

1. What different properties of mercury are used in the operation of a thermometer and of a barometer ?

2. Explain the difference between holding a burning match in the fingers and holding the end of a short piece of copper wire when the other end is in a gas flame.

3. Will heat from a source of high temperature pass through a vacuum ? Give an example.

4. Give two reasons why a bicycle pump becomes hot when pumping up a tire.

5. A gas stove has two burners, burner A using much more gas than burner B. Over which of these would you place a teakettle to heat it to the boiling point ? Why ? Over which would you place it to keep it boiling ? Why ?

6. Explain why the uncovered pipes of an ammonia ice machine are covered with ice.

7. Why is dew formed on grass ? Why is frost formed ? Explain the difference.

8. Give an example of the transformation of mechanical energy into heat. Give an example of the reverse.

IX. Electricity.

1. How could you determine the kind of electrification of charged bodies by the use of a positively charged pith ball ?

2. How can a body be charged by induction?

3. How does a lightning rod tend to prevent the destruction of buildings by lightning?

4. Find the resistance of 1000 ft. of copper wire having a diameter of 0.0201 in., the value of K being 10.38.

5. Write Ohm's law in three ways, each in the form of a sentence.

6. Six cells are coupled in series with an external resistance of 12 ohms. What current will they send if each cell has an E. M. F. of 1.5 volts and an internal resistance of 0.4 ohms?

7. What current will a battery of 4 dry cells coupled in parallel send through 100 ft. of No. 18 copper wire, the E. M. F. of each cell being 1.5 volts and its internal resistance 0.6 ohms?

8. In what direction would you send the current around an electromagnet in order to make the end that faces you the north pole?

9. Make a diagram, showing how a single bell may be rung by each of two push buttons.

10. Make a diagram showing how a single push button may ring two bells at the same time.

11. Two parallel circuits of 3 and 5 ohms respectively are coupled to two binding posts having a potential difference of 20 volts between them. What is the parallel resistance of the two circuits? What is the current in each branch? What is the total current?

12. A 60-watt Mazda lamp is run on a 110-volt circuit. What current does it take? What is its resistance?

X. Light.

1. How do we see a luminous body? How do we see a non-luminous body?

2. A man is reading at a certain distance from an incandescent lamp and finds the light too poor. He turns on another similar lamp from the same bracket. How much is the illumination increased? How much would it have been increased if he had moved halfway to the lamp instead of turning on the second lamp?

3. A certain projecting lamp makes a picture too large for the screen. What kind of a lens would you combine with the projecting lens of the lantern to reduce the size? Why?

4. What is the advantage of using a frosted bulb lamp instead of a clear glass bulb?

5. What is the advantage of putting a white glass globe on a lamp bulb?

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